Co-Benefits Analysis of Air Pollution and GHG Emissions for Hyderabad, India

Integrated Environmental Strategies Program
Washington, DC, USA
http://www.epa.gov/ies

Prepared by
Dr. Sarath Guttikunda
New Delhi, India

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Disclaimer

The analysis and views expressed in this report are entirely those of the authors. They do not necessarily reflect the views of the project sponsors—the United States Environmental Protection Agency (U.S. EPA) and the National Renewable Energy Laboratory (NREL)—or the countries they represent.

This report was prepared by Dr. Sarath Guttikunda, consultant, India, (E-mail: sguttikunda@gmail.com) in consultation with local and international partners.

For details on the Integrated Environmental Strategies (IES) Program, please contact Mr. Jack Fitzgerald, Program Manager, U.S. EPA (E-mail: fitzgerald.jack@epa.gov) or Ms. Monisha Shah, Program Coordinator, NREL (E-mail: Monisha_Shah@nrel.gov).

For details on the source apportionment program in Hyderabad, please contact Dr. K. V. Ramani, Joint Chief Environmental Scientist, Andhra Pradesh Pollution Control Board, India (E-mail: jces@pcb.ap.gov.in). For details on the emissions and co-benefits analysis, please contact Dr. Sarath Guttikunda, consultant, India..

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Acknowledgements

The Integrated Environmental Strategies (IES) Program in India is sponsored by United States Environmental Protection Agency (U.S. EPA) and coordinated by the National Renewable Energy Laboratory (NREL) in Washington, DC, USA.

Phase 1 of the IES-India project was coordinated by Environmental Protection Training and Research Institute (EPTRI) in Hyderabad, India, and focused on the co-benefit analysis of air pollution and greenhouse gas (GHG) emissions, with 2001 as the base year.

Phase 2 of the project is a two-part study. The first part was coordinated by Andhra Pradesh Pollution Control Board (APPCB), Hyderabad, India, with co-financial support from APPCB and the World Bank. Desert Research Institute (DRI) (Reno, Nevada, USA) provided the technical expertise for the source apportionment component of the study. The second part, conducted in consultation with APPCB, included air pollution and GHG emission co-benefits analysis, with 2006 as the base year.

Web Sites:

APPCB:	http://www.appcb.org
EPTRI:	http://www.eptri.com
DRI:	http://www.dri.edu
NREL:	http://www.nrel.gov
IES:	http://www.epa.gov/ies
U.S. EPA:	http://www.epa.gov
The World Bank:	http://www.worldbank.org

Abbreviations & Acronyms

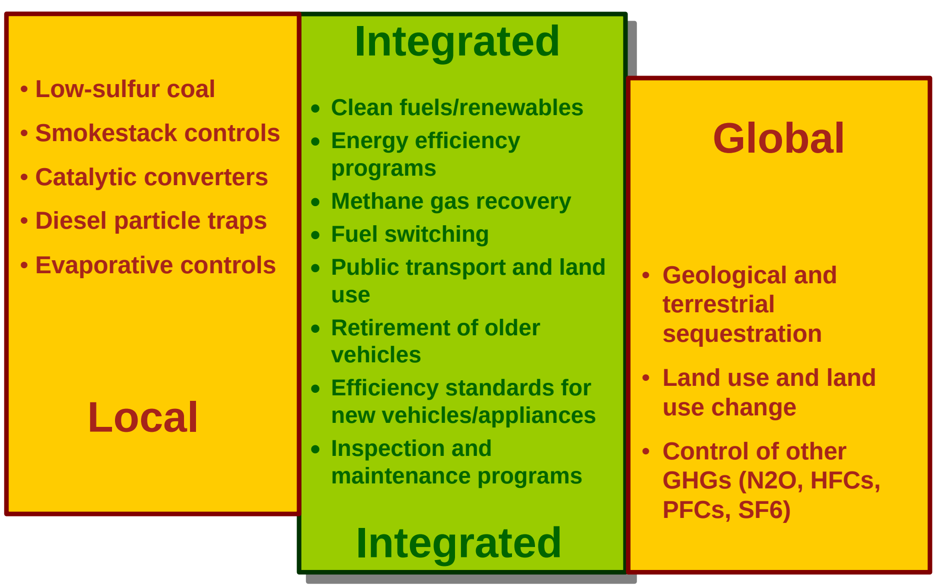
APPCB	Andhra Pradesh Pollution Control Board
AQM	Air Quality Management
CDM	Clean Development Mechanism
CMB	Chemical Mass Balance
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPCB	Central Pollution Control Board
DRI	Desert Research Institute
EPCA	Environmental Pollution (Prevention & Control) Authority
EPTRI	Environmental Protection Training and Research Institute
GHG	Greenhouse Gases
HUDA	Hyderabad Urban Development Area
IDA	Industrial Development Area
IES	Integrated Environmental Strategies
IT	Information Technology
km	Kilometer
LPG	Liquefied Petroleum Gas
MCH	Municipal Corporation of Hyderabad
MiniVol	Airmetrics Minimum Volume Sampler
MMTS	Multi-Modal Transport System
NAAQM	National Ambient Air Quality Management
NEERI	National Environmental Engineering Research Institute
NO_x	Nitrogen Oxides
NREL	National Renewable Energy Laboratory
OC	Organic Carbon
PIXE	Proton Induced X-ray Emissions
PM	Particulate Matter
PM_{10}	Particulate Matter with diameter $< 10\ \mu m$
$PM_{2.5}$	Particulate Matter with diameter $< 2.5\ \mu m$
PPSA	Particulate Pollution Source Apportionment
RSPM	Respiratory Suspended Particulate Matter
SAAQM	State Ambient Air Quality Management
SO_2	Sulfur dioxide
THC	Total Hydrocarbons
TSPM	Total Suspended Particulate Matter
U.S. EPA	United States Environmental Protection Agency
VKT	Vehicle Kilometers Traveled
WTP	Willingness to Pay
XRF	X-Ray Fluorescence
$\mu g/m^3$	Concentration in Micrograms per Cubic Meter

Chapter

1. Integrated Environmental Strategies Program

Environmental management requires an integrated approach, consolidating technical, economic, physical, and ecological aspects. The Integrated Environmental Strategies (IES) Program promotes integrated planning to address local environmental concerns, as well as reduce associated global greenhouse gas (GHG) emissions. The program encourages developing countries to analyze and implement policy, technology, and infrastructure measures with multiple public health, economic, and environmental benefits. To date, government agencies and research institutions in Argentina, Brazil, Chile, China, India, Mexico, the Philippines, and South Korea have participated in the IES Program.

Figure 1.1: Co-benefits of Integrated Programs



Source:: Dr. Jason West, University of North Carolina, Chapel Hill, USA

The IES Program uses a country-driven approach. Country programs are tailored to address local and national needs and priorities and build lasting capacity. In-country research teams, guided by policymakers and assisted by U.S. counterparts, identify key policy objectives and a range of conventional and innovative policy measures. The team analyzes the potential co-benefits of selected mitigation strategies and makes recommendations that inform policy decisions.

Co-benefits analyses, outlined in Figure 1.1, have primarily focused on estimating the human health benefits resulting from air quality improvements associated with increased use of clean energy technologies and measures. IES analysis could be extended to quantify additional benefits, such as economic development impacts (e.g., job creation, trade balance) and reduced traffic congestion.

The IES framework is designed for interdisciplinary, yet independent, technical teams working towards the common goal of identifying cost-effective policies and technologies that produce the desired co-benefits. The U.S Department of Energy's National Renewable Energy Laboratory (NREL) provides technical support for the program.

1.1 Phase 1 of IES Hyderabad, India

The United States Agency for International Development/India Mission and U.S. EPA launched the IES-India project in February 2002. The team selected the city of Hyderabad, capital city of Andhra Pradesh in the south, as the project site. Hyderabad is known for its emerging high-tech industry and its rapid growth in the past decade. Key government officials in the Ministry of Environment and Forests, Central Pollution Control Board (CPCB), Andhra Pradesh Pollution Control Board (APPCB), and the Municipal Corporation of Hyderabad (MCH) supported the IES effort, starting with a scoping meeting in February 2002 identifying the following specific project objectives:

- Provide policymakers with quantified information on the public health, environmental, and economic impacts of selected integrated measures to improve ambient air quality.
- Engage policymakers and other key stakeholders in a discussion on the benefits of an integrated approach to addressing environmental problems.
- Build support among key stakeholders, including public officials, businesses, nongovernmental organizations, and civic organizations, for the effective implementation of promising measures.
- Build capacity in Hyderabad and India for multidisciplinary policy analysis.

The Environmental Protection and Training Research Institute (EPTRI) served as the lead technical partner and project coordinator, and the Institute of Health Systems led the air pollutant health effects assessment. The team conducted preliminary analysis on Hyderabad's transportation planning in coordination with an U.S. EPA. U.S. EPA, ICF Consulting[1], and the Indian partner RITES[2] (a consulting group affiliated with Indian Railways) developed transportation planning scenarios to reduce traffic congestion, improve air quality, and reduce associated GHG emissions in the city.

The IES-India team, led by EPTRI, quantified the multiple benefits of the scenarios developed by RITES. A thorough and transparent emission inventory of stationary and transportation combustion sources was compiled for Hyderabad[3]. The emission inventory included both ambient air pollutants (particulate matter [PM], sulfur dioxide [SO_2], and nitrogen oxides [NO_x]) and GHGs (carbon dioxide [CO_2], methane, and nitrous oxide) for the calendar year 2001. The results of the emission inventory and subsequent air quality modeling concluded that the primary source of PM_{10} emissions (PM with aerodynamic diameter less than 10 micrometers) was the transportation sector (approximately 62 percent) followed by the industrial sector.

In June 2004, the IES-India team presented its final report and its key findings, including cost-benefit analysis and recommendations, to government officials at the central, state, and municipal levels. Two nongovernmental organizations—Winrock International-India and the Confederation of Indian Industries—coordinated elements of the outreach campaign.

1.2 Phase 2 of IES Hyderabad, India

Phase 2 of the IES-India project was aimed at validating and improving the existing emission inventory to further assist environmental managers understand and better manage the air pollution and GHG emission sources.

Following the Indian Supreme Court ruling in August 2003 (see Box 1), APPCB decided to conduct a full-scale particulate pollution source apportionment (PPSA) study in the city of Hyderabad to identify the contribution of various sources—vehicles, dust, industrial coal and oil combustion, and biomass burning. The PPSA study is one half of Phase 2 of the project, followed by updating the source contributions; identifying pollution source strengths; and the performing a co-benefits analysis of the Hyderabad city air pollution reduction action plan.

Main objectives of this phase are:

- To conduct a source apportionment study in Hyderabad, India, that builds on the existing emission inventory.

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[1] ICF Consulting Inc., Washington DC, USA. http://www.icfi.com

[2] RITES, a Government of India Enterprise, New Delhi, India. http://www.rites.com

[3] Reports and analysis results from IES Phase 1 are available at http://www.epa.gov/ies/india.htm

- To confirm the major sources of respirable suspended PM (PM_{10} and $PM_{2.5}$) and improve and validate the existing emission inventory.
- To train and build capacity in Hyderabad (with the APPCB and associated technical institutions) in source apportionment analysis and application to assist with GHG and air quality management (AQM) decisions.
- To strengthen APPCB's environmental management and decision-making capacity.
- To support industrial and transportation measures that integrate clean energy technologies with environmental management techniques.
- To provide APPCB with sufficient data to support integrated policies aimed at reducing both ambient PM levels and GHG emissions.

Box 1: Need for Particulate Pollution Source Apportionment Study

Supreme court directive on August 14th, 2003.

"CPCB's report shows that the Respirable Suspended Particulate Matter (in short "RSPM") levels in Ahmedabad, Kanpur, Sholapur, Lucknow, Bangalore, Chennai, Hyderabad, Mumbai and Kolkata are alarming. It has been observed therein that air pollution is a serious problem and therefore, some measures are required to be taken immediately. …..…….Issue notices to the States of Maharashtra, Andhra Pradesh, Gujarat, Uttar Pradesh, Karnataka and Tamil Nadu. In the mean time, we direct that the Union of India and the respective States shall draw a plan for lowering the rate of RSPM level in the aforesaid cities. After the plan is drawn, the same would be placed before EPCA. This may be done within a period of two months. We are excluding Mumbai and Kolkata where the respective High Courts are stated to be monitoring the RSPM levels in those cities. EPCA after examining the matter shall submit a report to this Court within a period of four weeks thereafter."

Source: *APPCB, Hyderabad, India*

Table 1.1: Roles and Responsibilities of PPSA Project Partners

Institution	Role and Responsibilities
APPCB (Hyderabad, India)	Provided in-country leadership and coordination, including technical staff to assist with the monitoring, site preparation, sample collection, and analysis.
DRI (Reno, Nevada, USA)	Provided technical support, including in-country training for technical staff on sampling and sample analysis.
U.S. EPA and NREL (Washington D.C., USA)	Provided overall project guidance, including coordination of project partners, facilitation of training programs, and providing guidance on program development and analysis.
World Bank (Washington D.C., USA)	Provided technical support and guidance, in-country support and training with sampling, and the coordination of sample analysis with DRI.

This study was conducted in collaboration with APPCB, NREL, U.S. EPA, and the World Bank. Technical and analytical coordination was provided by DRI and local consultants. Roles and responsibilities of individual institutions are explained in Table 1.1. It is hoped that this project will enhance capacity for subsequent source apportionment and co-benefits analysis studies in India.

Table 1.2: IES-India Phase 2 Project Schedule

Time Period	Activities
November 2005	First training and capacity-building session at APPCB; Survey of local institutions of source apportionment analysis; First phase sample collection and analysis
May 2006	Second phase of sample collection and analysis, followed by QA/QC session for independent third phase
October 2006	Final phase of sample collection and analysis; Chemical analysis at DRI
December 2006	Presentation of preliminary results at Better Air Quality for Asian Cities conference in Jogjakarta, Indonesia.
August 2007	Receptor modeling and final analysis; Drafting of final report
November 2007	Project wrap-up and submission of draft final report
December 2007	Share results with local and national policymakers; Workshops at CPCB (New Delhi, India) to share results and methodology with national agency, Habitat center (New Delhi, India) to share results with national and international counterparts; and APPCB (Hyderabad, India) to share results with local institutions
March 2008	Submission of final report to IES Program

1.3 Scope of the Study

Major sources of air pollution in urban areas include combustion processes (e.g., burning fossil fuels for steam and power generation, heating and household cooking, waste burning, gasoline and diesel-fueled engine combustion) and various noncombustion industrial processes (e.g., solvent extraction processes). One of the key factors in implementing a successful AQM plan is gaining a better understanding of the local and regional pollution sources.

The primary focus of this study is PM, due to its strong correlation to adverse human health effects, and measures to reduce PM and GHG emissions simultaneously.

Chapter

2. Hyderabad Air Quality

Rapid urbanization of the cities combined with growing demand for energy resources and exponential growth of vehicular fleets are contributing to deteriorating air quality in urban centers. Along with lack of corresponding infrastructure to accommodate the burgeoning traffic volume, growing levels of congestion are adding to the local pollution problems. Other important sources of pollution are coal and oil combustion at industrial sites. In the coming years, given the economic trends in cities in developing country, motorized transport is only expected to increase, further threatening air quality.

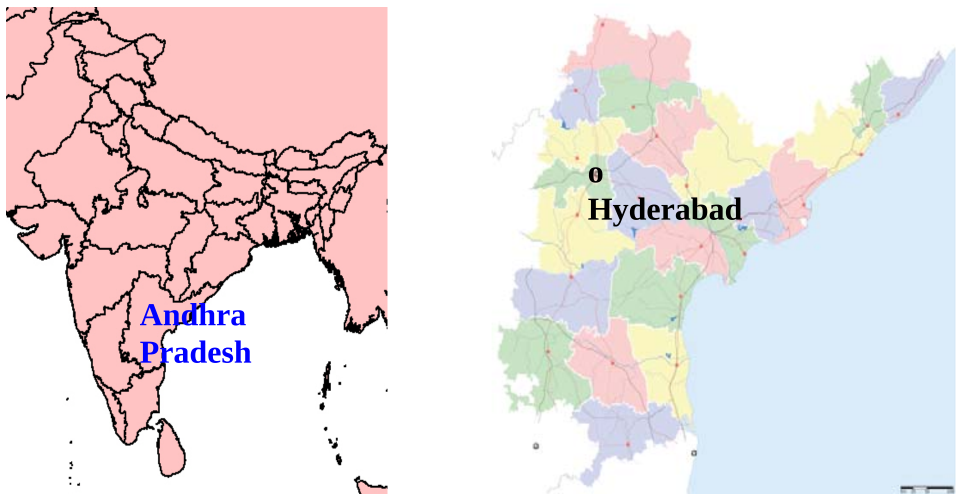
Poor air quality, in turn, has been shown to have serious effects on public health. In particular, PM is a major concern, as it is small enough to penetrate deep into the lungs and pose significant health risks.

2.1 Hyderabad, India: Background

Hyderabad, a 400-year-old city, is the state capital of Andhra Pradesh. It lies on the Deccan Plateau, 541 meters (1776 ft) above sea level, over an area of approximately 625 km^2. Hyderabad, along with its twin city of Secunderabad, is the fifth largest city in India, with a population nearing 7 million. Due to its prominence as a major high-tech center, it is one of the fastest growing areas, with a population density of ~17,000 persons/km^2. The rapid rate of urbanization with increased economic activity has encouraged migration to the twin cities, which led to an increase of personal, public, and para (3 and 6 seat autos) transit vehicles; industrial output; and increasing burden on the cities' infrastructure. Hyderabad, along with the surrounding 10 municipalities, constitutes the Hyderabad Urban Development Area (HUDA) and has been growing at an average rate of 9 percent per year.

Growing levels of urbanization have resulted in increased air pollution due to higher activity in the transportation, energy, and industrial sectors, which are all concentrated in densely populated urban areas. Figure 2.2 presents a map of major industrial development areas (IDA). Even with the clean and green initiatives, there still remains a tremendous amount of potential to reduce the air pollution impacts on public health, especially with the increasing demand for infrastructure and services in HUDA.

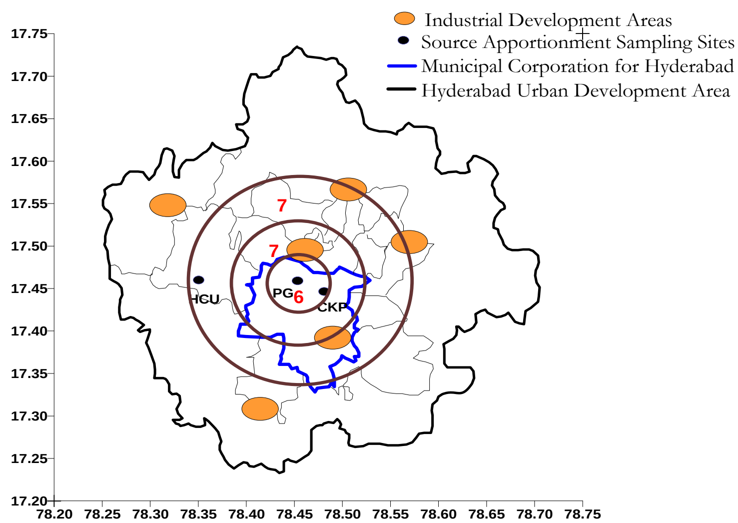
Figure 2.1: Geographical Location of Hyderabad



2.2 Air Pollution Monitoring in Hyderabad

Prior to this study, APPCB operated 20 monitoring stations in Hyderabad. A circular grid network is presented in Figure 2.2. For this grid network Punjagutta (PG on map) is considered the center of the circular grid.

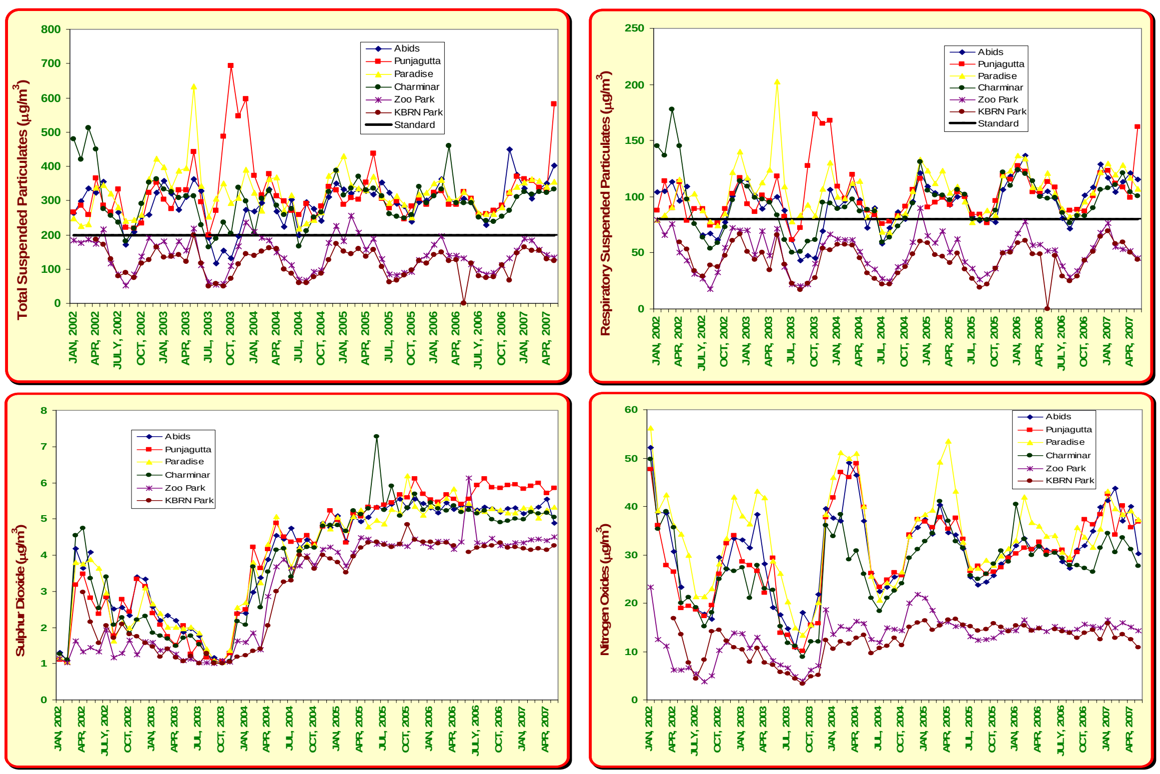
Figure 2.2: Major IDAs and Distribution of Monitoring Sites in Hyderabad, India



A distance of 5 km radius from Punjagutta is the inner grid forming the core of urban area. The next 5-km distance (penultimate grid) covers areas with high to moderate pollution. Similarly, the next 5-km distance (outer grid) covers areas with moderate to low pollution. In this grid, monitoring stations were installed in a phased manner. Three of the monitoring stations—Uppal, Balanagar, and Banjara Hills—have been in operation since 1992 for suspended particulate matter (SPM), NO_x, and SO_2. PM_{10} has been monitored since 1997.

All the stations are manually operated. Six stations are being operated under the National Ambient Air Quality Monitoring Programme[4], and the rest are operated under the State Ambient Air Quality Management Programme[5].

Figure 2.3: Monthly Average Pollutant Concentrations (µg/m³) in Hyderabad



Source: *APPCB, Hyderabad, India*

The monitoring station installed at the Punjagutta (point PG in Figure 2.2) police station is a real-time, on-line station measuring meteorological data, PM_{10}, carbon monoxide (CO), hydrocarbons, SO_2, and NO_x. Monitoring data from this station is connected to the Internet and available online at all times[6]. Monthly average concentrations for total suspended particulate matter (TSPM), PM_{10}, SO_2, and NO_x for six stations are presented in Figure 2.3. Two of the stations (Zoo Park and KBRM Park) are considered background sites, with less

[4] At Central Pollution Control Board (CPCB), http://envfor.nic.in/cpcb/aaq/aaq.html
[5] At APPCB, http://www.appcb.org/environ_q/environment_q_undercons.htm
[6] http://www.appcb.org/pcb/online.htm

vehicular traffic passing through the premises. All six stations are within the 10-km radius of the city center.

Table 2.1: Annual Average Concentrations of TSPM (μg/m³) in Hyderabad

	Abids	*Punjagutta*	*Paradise*	*Charminar*	*Zoo Park*	*KBRN Park*
2002	278	284	293	336	147	126
2003	252	398	366	271	140	111
2004	280	308	303	272	142	115
2005	309	308	325	305	144	117
2006	312	302	306	296	130	110
2007	346	394	354	325	161	145

Table 2.2: Annual Average Concentrations of PM_{10} (μg/m3) in Hyderabad

	Abids	*Punjagutta*	*Paradise*	*Charminar*	*Zoo Park*	*KBRN Park*
2002	92	93	96	103	52	48
2003	80	112	112	80	48	40
2004	89	95	95	87	50	42
2005	96	96	103	98	48	40
2006	104	104	107	98	53	46
2007	114	121	120	109	56	56

Table 2.3: Annual Average Concentrations of NO_x (μg/m³) in Hyderabad

	Abids	*Punjagutta*	*Paradise*	*Charminar*	*Zoo Park*	*KBRN Park*
2002	30	27	34	28	10	11
2003	24	21	28	19	9	7
2004	33	35	36	27	15	12
2005	31	32	36	31	15	15
2006	32	32	34	30	15	14
2007	38	38	40	31	15	13

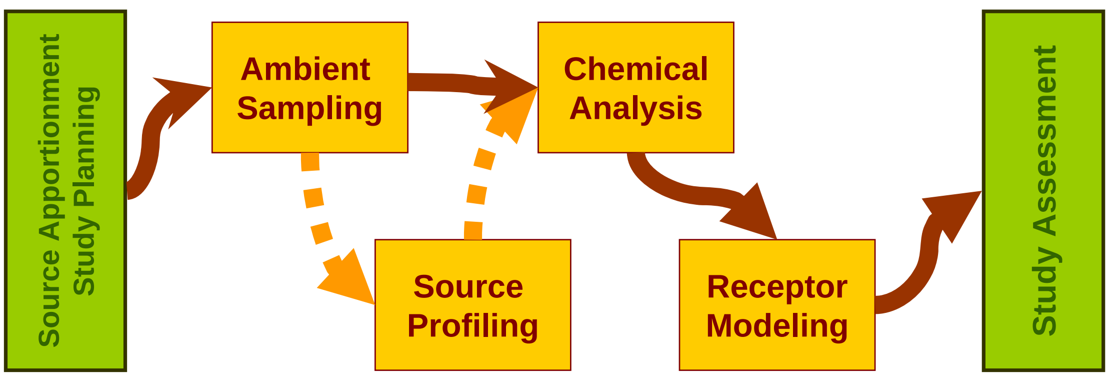
Following Figure 2.3 and Tables 2.1 through 2.3, the increasing air pollution problems have necessitated the source apportionment of air pollutants for better management of air pollution sources. The first four stations—Abids, Punjagutta, Paradise, and Charminar—are the largest traffic junctions in the city and measure high air pollution, likely influenced by higher vehicular movement. The big increase in the TSPM at these stations is also due to increased vehicular activity in the vicinity and resuspension of dust on paved and unpaved roads. With the growing pollution levels in the city comes the challenge of making informed decisions for pollution control. One of the major inputs for such decision-making is a better understating of pollution sources.

Chapter

3. Source Apportionment Study in Hyderabad

The particulate pollution source apportionment study was conducted under Phase 2 of the IES-India project, in collaboration with APPCB, NREL, U.S. EPA, and the World Bank, to quantify PM pollution source contributions and assess the potential for improving local air quality and reducing GHGs simultaneously.

Figure 3.1: Overview of Particulate Pollution Source Apportionment Study



This project, initiated in 2005, was intended to introduce, demonstrate, and apply source apportionment techniques to assist AQM in Hyderabad. An outline of various activities under PPSA is depicted in Figure 3.1. This study is intended to provide a unique opportunity to evaluate the emission inventory from IES Phase 1, generate detailed information on the chemical composition of ambient PM, further strengthen data support for policymakers, and improve AQM in Hyderabad. Specific objectives of this study included:

- Conduct a source apportionment study in Hyderabad
- Determine the major sources contributing to elevated levels of PM
- Improve and validate the existing emission inventory
- Train and build capacity on PM source apportionment application
- Provide data to support policies to reduce PM and GHG emissions

As a part of the project, a training workshop was held in November 2005 to train and build capacity at APPCB with aspects of PPSA analysis ranging from equipment needs, placement of monitoring equipment, sample collection, chemical analysis, and receptor modeling. The training was conducted by technical staff from DRI and the World Bank[7]. It is hoped that this project will enhance capacity for subsequent source apportionment studies in India. Training material and supporting documents are available on the IES Program Web site for reference and use.

3.1 Sampling and Analytical Design

In November 2005, a team consisting of staff from DRI, NREL, and the World Bank surveyed eight sites in Hyderabad; three were selected based on the location of the sites, surroundings, meteorology, and mix of source strengths in the neighbourhood. Selected site locations are presented in Figure 2.2 (blue dots). A detailed report on the monitoring sites survey and the PPSA methodology is available separately on the IES-India project Web site.

The sampling was conducted in three phases over a period of one year for one month for each phase. The three phases were selected based on the climatic conditions to represent the three predominant seasons: Phase 1 (November 12 - December 1, 2005) for winter; Phase 2 (May 9 - June 9, 2006) for summer; and Phase 3 (October 27 - November 18, 2006) for rainy.

3.1.1 Description of Monitoring Sites

Description of the three monitoring sites is provided below, along with a pictorial description of the surroundings in Figure 3.2.

Site 1: Punjagutta

This site represents a highly commercial and moderately residential area to the northwest of Hussain Sagar Lake. The major pollution sources are vehicles, resuspension dust, and biomass fuel combustion by restaurants. Additionally, Punjagutta is a major transit point for traffic, with the highest traffic junction density. The sampling site is located on top of the Punjagutta police station at ~10 m above ground.

Site 2: Chikkadpally

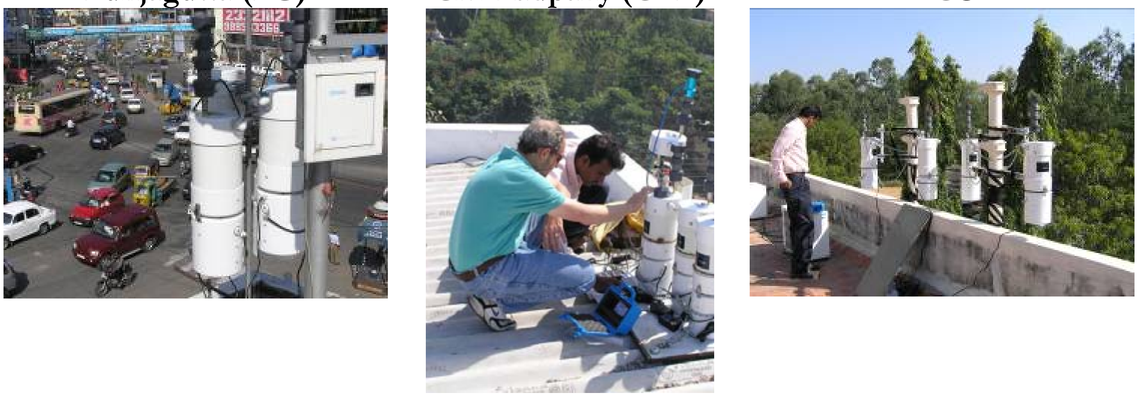
This site represents a moderately commercial and highly residential area, located to the southeast of Hussain Sagar Lake. Major roads around the station are lined with shops and commercial enterprises. The city central library and 20 cinemas make it a high public access point. The major sources of pollution are restaurants and industrial chimneys, vehicle traffic, and resuspension dust. The sampling site is located on top of the Chikkadpally police station at ~10 m

[7] Workshop material is also available for download at
http://www.epa.gov/ies/india/apportionment_documents.htm#2005%20workshop

above ground, clear from all obstacles and with a constant power supply and safety equipment.

Figure 3.2: Sampling Sites in Hyderabad, India

Punjagutta (PG) **Chikkadpally (CKP)** **HCU**



<u>Site 3: HCU</u>

This site is 15 km away from the city. It is predominantly a downwind site in winter and is upwind for rest of the seasons. This site is relatively free from any direct sources of pollution. It has been designated as sensitive and is located on the old Hyderabad-Mumbai Highway with limited local vehicular traffic. The university stretches over 2,300 acres of land, with a sprawling, scenic, and serene campus. The sampling site is located on top of the administrative building at approximately 15 m above ground.

3.1.2 Instrumentation

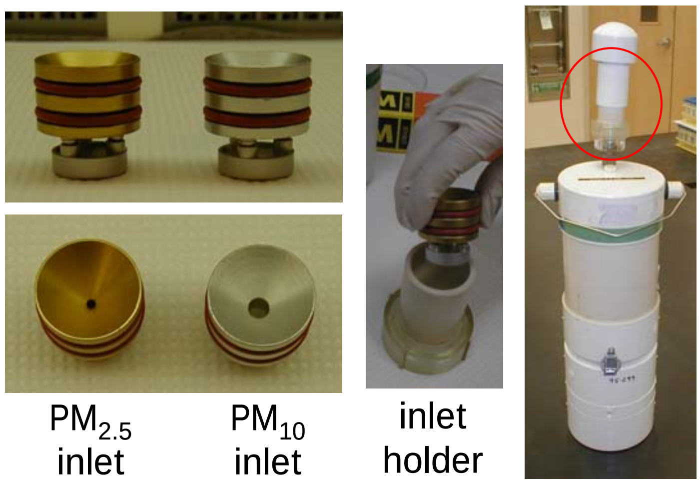
For the PPSA study in Hyderabad, aerosol samples were collected using 12 *<u>MiniVol Portable Air Samplers (Minivol)</u>*[8] operating for 24-hour sampling periods.

The Airmetrics Minivols are configured to collect $PM_{2.5}$, PM_{10}, or TSP samples. However, only one size fraction can be measured at a time. The MiniVol pump draws air at 5 liters/min through a particle size separator (impactor) and then through 47mm Quartz and Teflon filters. The PM_{10} and $PM_{2.5}$ separation is achieved by impaction, or a TSP sample can be collected by removing the impactor(s). Figure 3.3 presents an assembly of the sampler, widely used for source apportionment studies around the world.

Main advantages of using MiniVol samplers are that they are relatively inexpensive at $3,500 US per piece (compared to the samplers available in the market), flexible to use for PM_{10} and $PM_{2.5}$, portable, easy to operate and maintain, and can be operated by battery (in the event of power outage).

[8] Minivol Sampler - http://airmetrics.com/products/minivol/index.html

Figure 3.3: Minivol Sampler and PM Filter Assembly



3.1.3 Chemical Analysis and Modeling

Interpretation of the results from the analytical work was conducted by a joint USA-India team consisting of APPCB, DRI, and local consultants.

In order to meet the time, equipment, and analytical needs, APPCB selected DRI to complete the chemical analysis of all three sampling periods. Following sample collection, filters were shipped to DRI for chemical analysis.

- Teflon filters were analyzed for gravimetric mass and metals using X-Ray florescence
- Quartz filters were analyzed for ions using ion chromatography and automated calorimetry
- Organic and elemental carbon were analyzed using thermal/optical reflectance
- Soluble potassium was analyzed using atomic absorption spectrometry.

Chemical analysis of the PM features included particle size, shape, and color; particle size distribution (number); component identification (organic, inorganic, and radioactive); component chemical state; concentration; and spatial variations. Although most of these features can be used to identify source types, the only features that can be used to determine source contribution quantitatively are component concentrations or number of particles of a specific type and size, as described in the source profiles[9].

[9] Guttikunda et al., 2008. "Handbook of Particulate Pollution Source Apportionment Techniques." The World Bank, Washington DC, USA.

The most common methods utilized for receptor modeling are the Chemical Mass Balance (CMB) model, positive matrix factorization, principal component analysis, factor analysis, and constrained physical receptor model. For the Hyderabad case study, CMB version 8.2 was utilized.

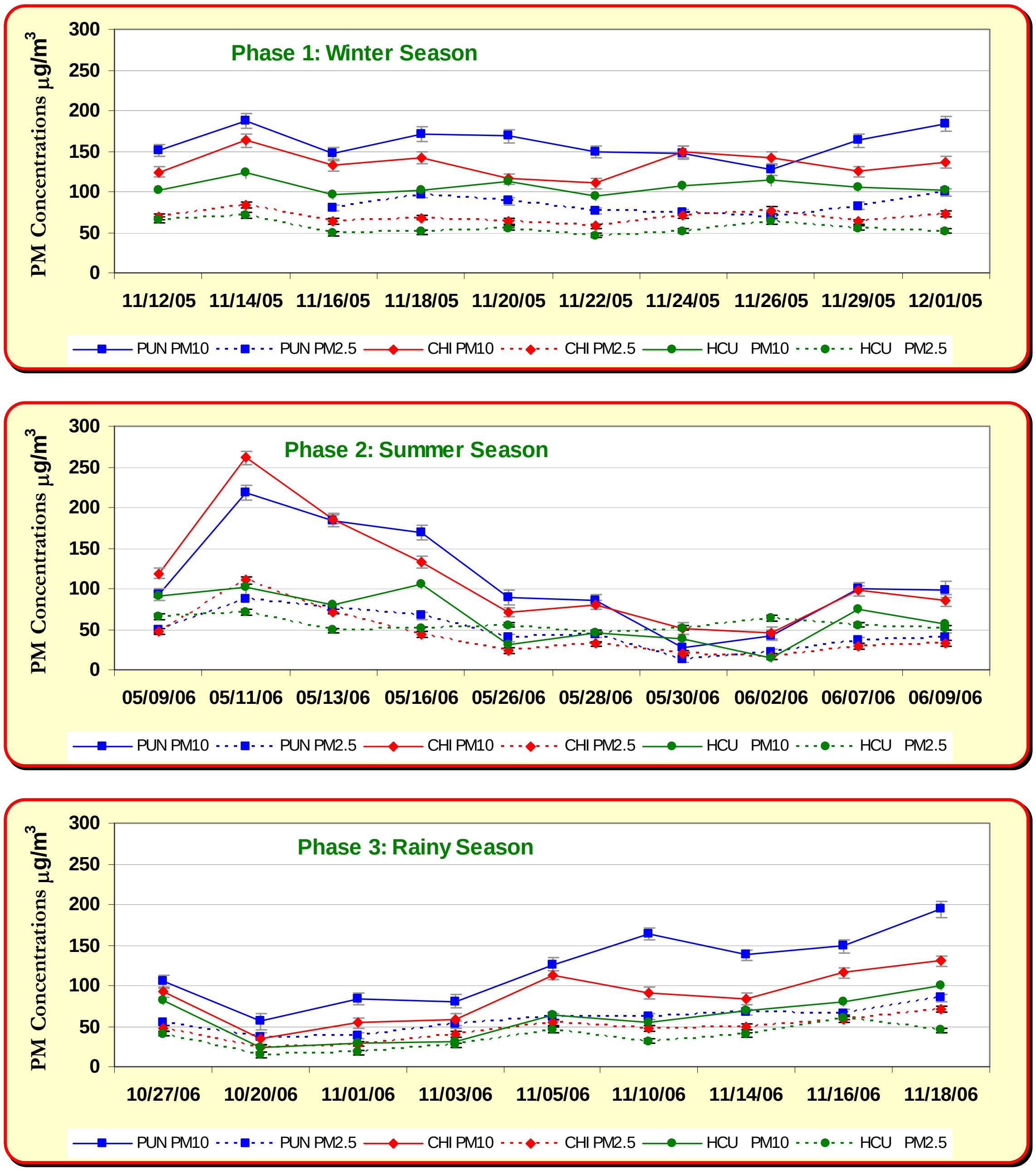
The *CMB model*[10] is one of several receptor models that have been widely applied to source apportionment studies. The latest version of CMB version 8.2 is Windows-based and includes menu-driven operation. The model requires speciated source profiles of potential contributing sources and the corresponding ambient data from analyzed samples collected at a single receptor site.

3.2 Monitoring Results

Punjagutta measured the highest average PM_{10} (160 µg/m^3), as well as $PM_{2.5}$ (86 µg/m^3) gravimetric levels during the Batch 1, exceeding the PM_{10} standard (150 µg/m^3) on six of the 10 measured days. In the absence of national standards for $PM_{2.5}$, the data is compared with U.S. EPA standards of 60µg/m^3, which was exceeded on all 10 sampling days. Chikkadpally was slightly less polluted with one exceedance for PM_{10} and nine for $PM_{2.5}$ over the 10-day period. HCU was substantially cleaner, with approximately 70 percent of the levels measured for the two city center sites for PM_{10}, and similarly for $PM_{2.5}$. There were no measured exceedances for PM_{10}, and three of the 10 days exceeded the standard for $PM_{2.5}$. The $PM_{2.5}/PM_{10}$ mass ratios are in the narrow range of 0.51 – 0.54 for Batch 1, 0.38 – 0.42 for Batch 2, and 0.58 – 0.64 for Batch 3—evidence of a uniform regional $PM_{2.5}$ aerosol level for the HUDA region. Table 3.1 presents a summary of the monitoring results from the three sampling periods.

[10] Watson, et al., 1997. "Chemical Mass Balance Receptor Model version 8: User's Manual." Prepared for U.S. EPA, Research Triangle Park, NC, by DRI, USA. Latest version of the model, MS Windows-based, can be downloaded at http://www.epa.gov/scram001/receptor_cmb.htm

Figure 3.4: Time Series of Measured Mass Concentrations During the Three Phases

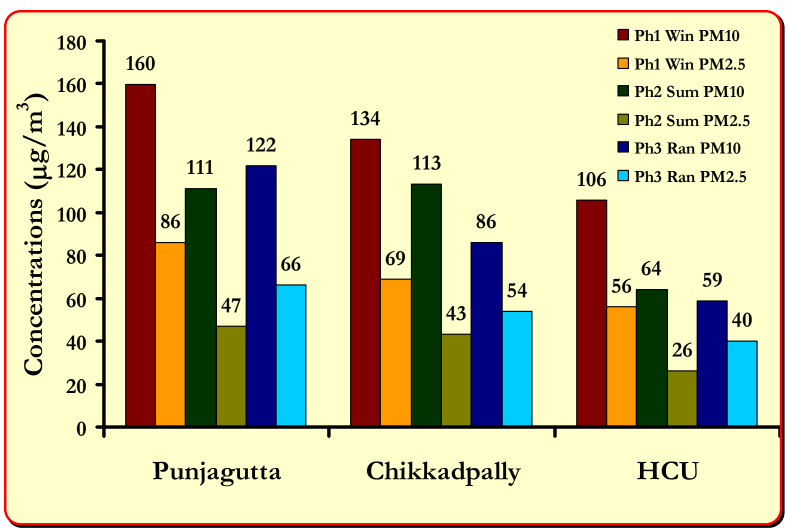


The PM_{10} concentrations are exceeding the Indian NAAQS standards prescribed for commercial and residential areas (100µg/m^3). HCU is exceeding the NAAQS prescribed for sensitive places (60µg/m^3). The concentration of PM_{10} and $PM_{2.5}$ in descending order is Punjagutta, Chikkadpally, and HCU. The concentration of PM_{10} at Punjagutta is at least 45 percent more than that of HCU and 17 percent higher than that of Chikkadpally. The higher concentration of PM is attributed mainly to the vehicles and resuspended dust, especially for traffic junctions of Punjagutta and Chikkadpally.

Table 3.1: Measured Mass Concentrations of PM_{10} and $PM_{2.5}$ During the Sampling Period

		PM_{10} (µg/m^3)			$PM_{2.5}$ (µg/m^3)		
S.No	Station name	Maximum	Minimum	Average	Maximum	Minimum	Average
Phase 1 (Summer)	Punjagutta	188	127	**160**	99	69	**86**
	Chikkadpally	163	110	**134**	84	57	**69**
	HCU	123	94	**106**	71	46	**56**
Phase 2 (Winter)	Punjagutta	218	28	**111**	87	13	**47**
	Chikkadpally	261	45	**113**	111	16	**43**
	HCU	105	14	**64**	75	6	**26**
Phase 3 (Rainy)	Punjagutta	193	56	**122**	136	36	**66**
	Chikkadpally	130	34	**86**	121	23	**54**
	HCU	100	23	**59**	61	15	**40**

Figure 3.5: Seasonal Variation of PM_{10} and $PM_{2.5}$ in Hyderabad



The mass concentrations are higher in winter and summer seasons. Figure 3.5 presents average concentrations for the three sampling periods. The concentrations in the summer season are initially very high, and the sudden drop in mass concentration at the end of the sampling period is due to an early onset of monsoon and rains due to cyclones. In the rainy season, there is a progressive increase of the concentrations at the end of the sampling period, which can be attributed to the gradual change in season from rainy to winter. Overall, summer and winter seasons are highly polluted. The ratio of $PM_{2.5}/PM_{10}$ is high in winter and averaged around 50 percent; in the summer and the rainy season the ratio is near 40 percent, indicating higher coarser fraction. The poor dispersion in the winter season followed by inversions and photochemical smog might have been the reason for the increase of $PM_{2.5}$ in the winter season.

3.3 CMB Receptor Modeling Results

Source attribution results of CMB modeling from the three sites are presented in Figures 3.6 through 3.8. In the absence of local source profiles from Hyderabad or India, profiles from other parts of the world were selected. Although several profiles from each source type were modeled, only those that provided reasonable statistics for all three sites and both size fractions were retained.

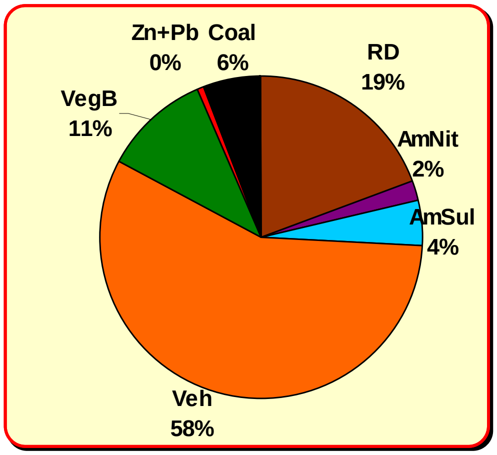
The source profiles selected represent known major source types contributing to the Hyderabad aerosol (i.e., an unpaved dirt road [soil] profile, a mobile source profile [petrol, compressed natural gas [CNG], and diesel mixed], and a coal combustion profile). Similar source profiles were selected that best model both PM_{10} and $PM_{2.5}$ ambient samples from all three sites.

Note: Legend for source apportionment results in the following figures

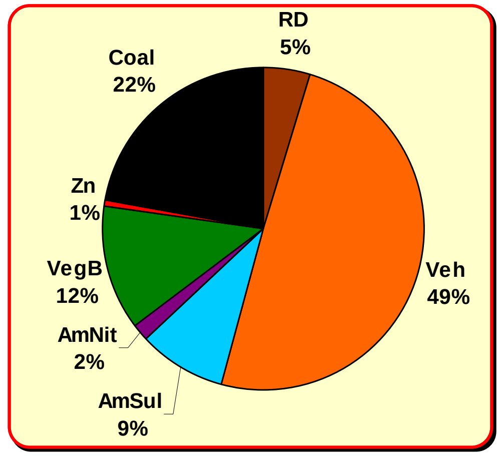
Coal
Vehiclar Activity (Veh)
Road Dust (RD)
Zn+Pb
Ammonium Nitrate (AmNit)
Ammonium Sulfate (AmSul)
Veg/Biomass Burning (VegB)
Cement (Cem)

Figure 3.6 Phase 1 (Winter) Source Apportionment Results for Hyderabad, India

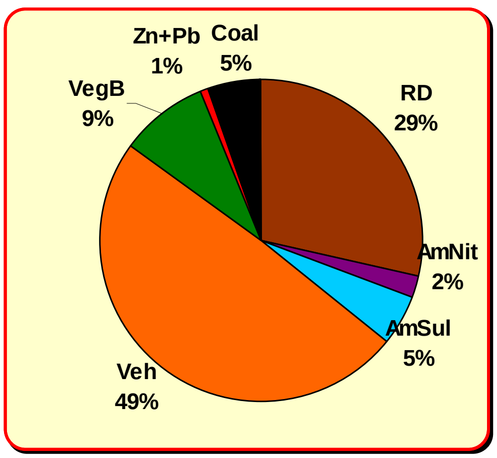
PG PM_{10} (Avg. Meas. Mass = 160 $\mu g/m^3$)



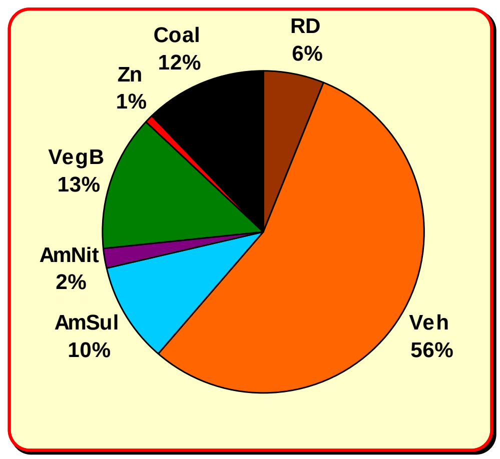
PG $PM_{2.5}$ (Avg. Meas. Mass = 86 $\mu g/m^3$)



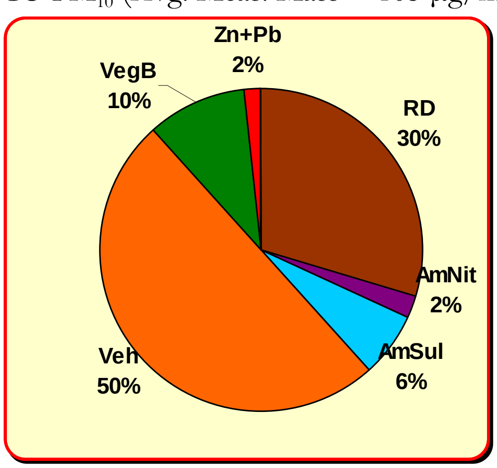
CKP PM_{10} (Avg. Meas. Mass = 134 $\mu g/m^3$)



CKP $PM_{2.5}$ (Avg. Meas. Mass = 69 $\mu g/m^3$)



HCU PM_{10} (Avg. Meas. Mass = 105 $\mu g/m^3$)



HCU $PM_{2.5}$ (Avg. Meas. Mass = 56 $\mu g/m^3$)

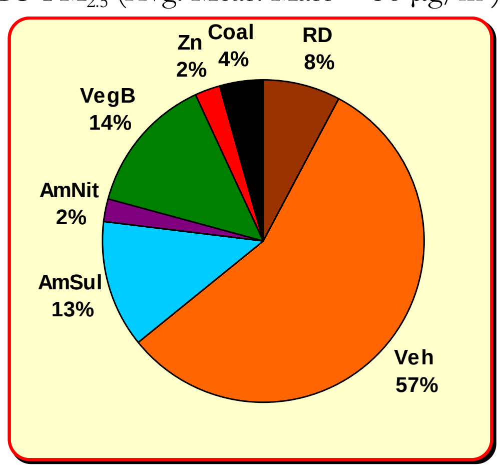
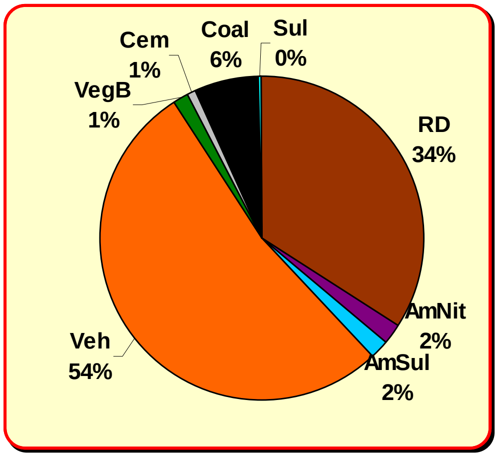
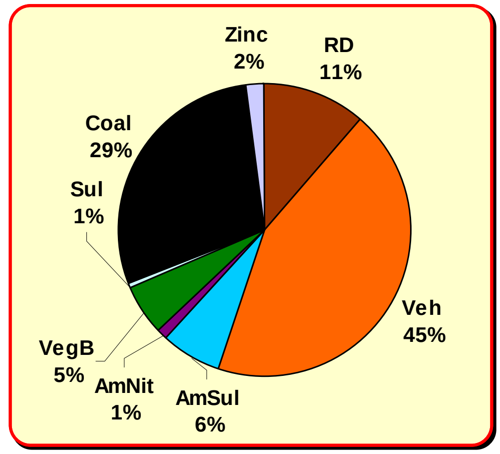


Figure 3.7 Phase 2 (Summer) Source Apportionment Results for Hyderabad, India

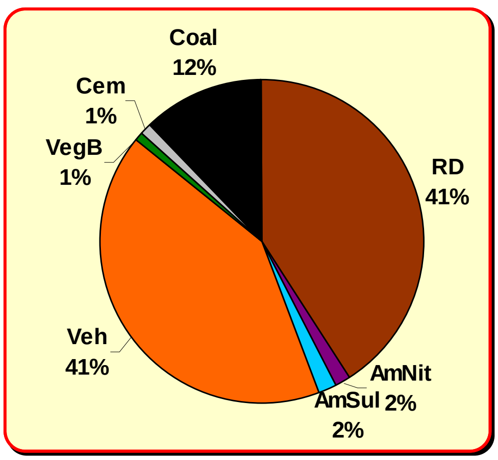
PG PM_{10} (Avg. Meas. Mass = 111 $\mu g/m^3$)



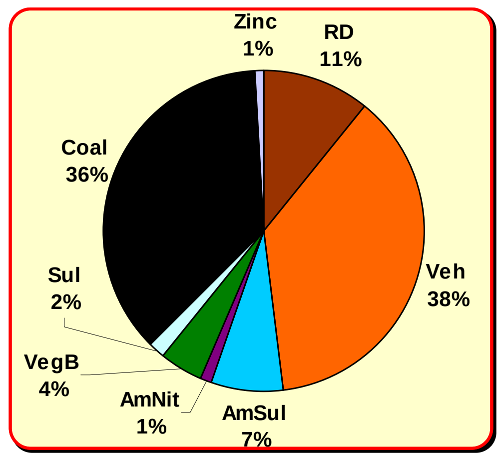
PG $PM_{2.5}$ (Avg. Meas. Mass = 47 $\mu g/m^3$)



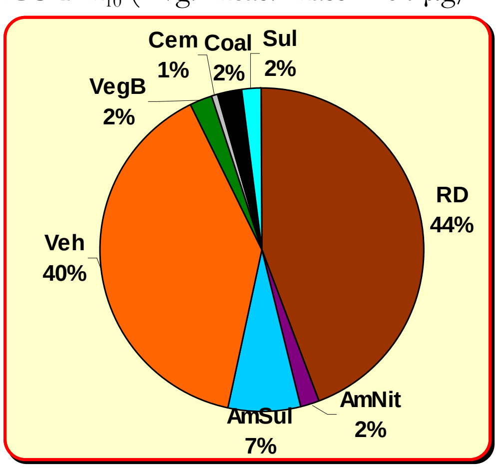
CKP PM_{10} (Avg. Meas. Mass = 113 $\mu g/m^3$)



CKP $PM_{2.5}$ (Avg. Meas. Mass = 43 $\mu g/m^3$)



HCU PM_{10} (Avg. Meas. Mass = 64 $\mu g/m^3$)



HCU $PM_{2.5}$ (Avg. Meas. Mass = 23 $\mu g/m^3$)

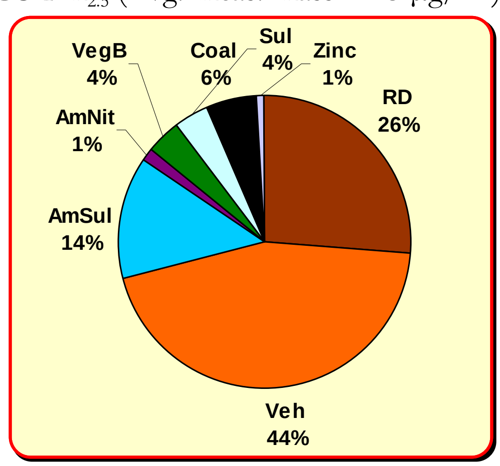
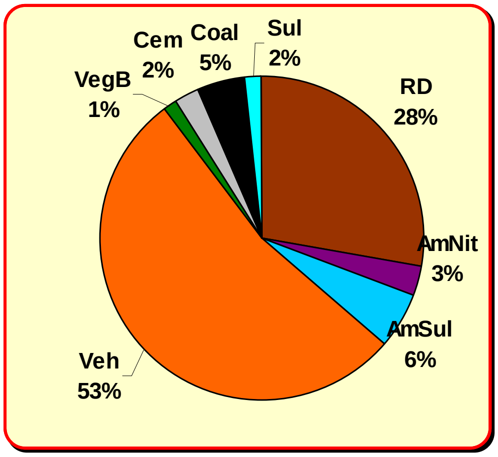
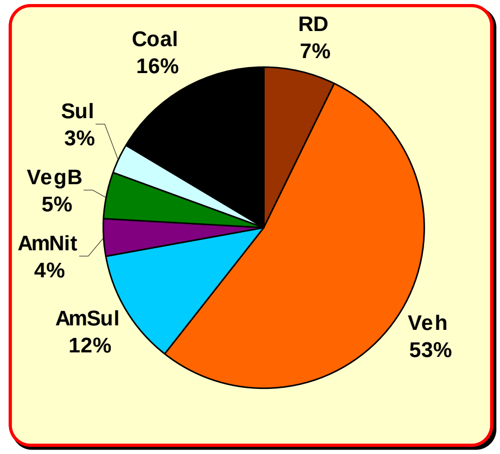


Figure 3.8 Phase 3 (Rainy) Source Apportionment Results for Hyderabad, India

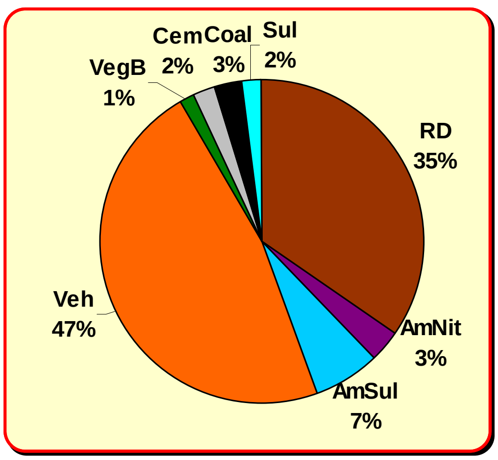
PG PM_{10} (Avg. Meas. Mass = 122 $\mu g/m^3$)



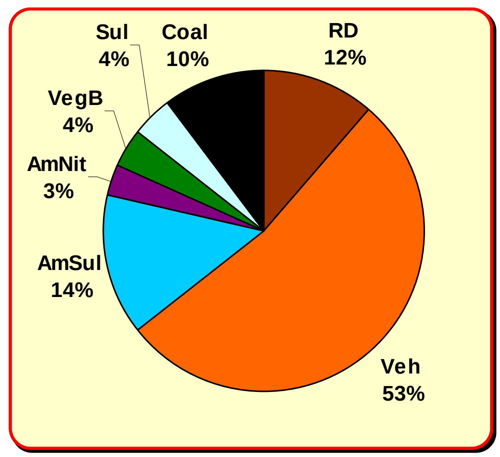
PG $PM_{2.5}$ (Avg. Meas. Mass = 66 $\mu g/m^3$)



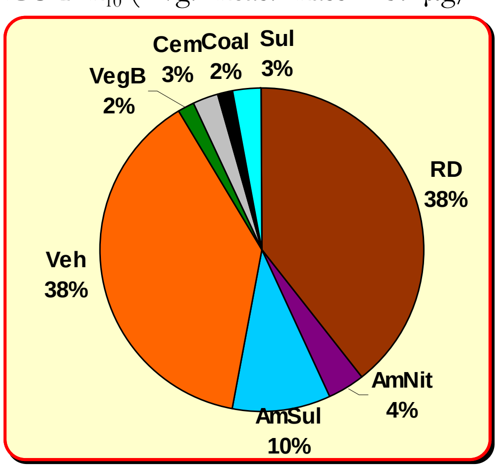
CKP PM_{10} (Avg. Meas. Mass = 86 $\mu g/m^3$)



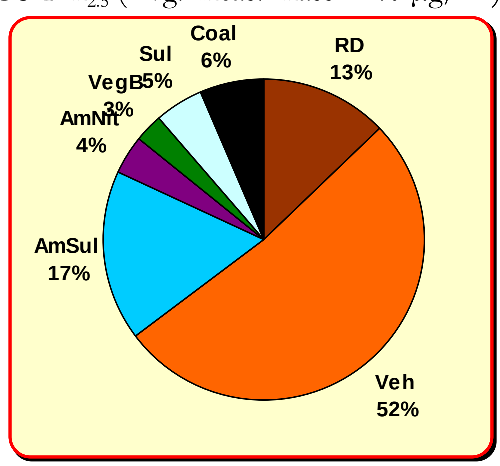
CKP $PM_{2.5}$ (Avg. Meas. Mass = 54 $\mu g/m^3$)



HCU PM_{10} (Avg. Meas. Mass = 59 $\mu g/m^3$)



HCU $PM_{2.5}$ (Avg. Meas. Mass = 40 $\mu g/m^3$)



The most important source measured throughout the sampling campaign was mobile sources, varying from 38 percent to 58 percent for PM_{10}, and 38 percent to 68 percent for $PM_{2.5}$. Unpaved road dust is the second largest source in PM_{10}, varying from 19 percent to 44 percent, and from 5 percent to 26 percent in $PM_{2.5}$. Biomass burning and ammonium sulfate also contributed significantly at the three sites, with ammonium nitrate always present at approximately 2 to 5 percent. Coal combustion varied between 0 and 36 percent, showing large uncertainties and incidences of long range transport of industrial sources outside the city center. This is also attributed to local coal combustion sources, such as cooking at Chikkadpally and Punjagutta, being few or absent at HCU.

The $PM_{2.5}$ fraction averaged about 50 percent of PM_{10} concentrations for the three sites and three periods. For the modeled species, values less than this mass ratio imply that a source, such as road dust (0.12 to 0.15), is concentrated in the coarser fraction, and values of 0.62 to 0.83 imply biomass source in the fine fraction. For the third phase, with $PM_{2.5}$ to PM_{10} concentrations in the 0.54 to 0.68 range, a stronger biomass (waste burning) signal is indicated, also predicted in the source apportionment result, ranging from 4 to 14 percent.

Major highlights of monitoring and CMB receptor modeling are:

- Ambient PM_{10} levels have increased over the last five years due to mixed growth in the city.
- Vehicular activity contributes significantly to increasing fine and coarse PM fractions.
- Of the vehicular contribution, the contribution of diesel is also increasing (in the form of BC and sulfates).
- Growing vehicular and construction activities lead to increased contribution of resuspended dust, especially in the fine fraction.
- Long-range transport of effluent gases and particles from industries around the city also increased during the sampling periods.
- Waste burning in residential areas, at landfills, and along the roadside is a notable source for fine PM.

3.4 Lessons Learned and Recommendations

As part of this study, the project team also included capacity building at APPCB at various stages of the project—preparation of sampling sites, operation of sampling equipment, sampling storage, chemical analysis, and receptor modeling. Due to the lack of full institutional setup to undertake all of these activities, some of them were conducted at DRI, in consultation with local authorities. Recommendations for future studies include the following.

- Measurement deployment must consider the level of confidence needed in the data, the uncertainly associated with the measurements, the resolution of the data, the intended use of the information, and local institutional capacity.

- Multiple measurement strategies—routine, special study, and intensive periods—are required to estimate human exposure, support epidemiological studies, identify the sources and understand the evolution of aerosols in the atmosphere, and track the success of implementation.
- The intended purpose of the data should drive the selection of the measurement method and spatial and temporal resolution of the measurement. The most effective measurement strategy requires a complement of long-term, routine measurements; focused special studies; and intensive field studies.

In the case of Hyderabad, the study focused on quantifying the contribution of various sources to the growing air pollution in the city. However, the study comes with a set of limitations that are very important to consider before any conclusions are drawn of the source apportionment results. Major limitations in the study include the following:

- For primary PM, there is reasonable success in apportioning to sources using specific source markers. In theory, this approach can distinguish between different types of vehicle exhaust, cooking, vegetative burning, vegetation fragments, etc. However, it is hard to distinguish between the sources utilizing similar fuels, such as diesel in industrial generator sets vs. diesel in vehicles.
- Given the large fraction of organic carbon (OC) in PM that cannot be identified through chemical analysis, there may also be more primary biogenic carbon compounds for which there are no clear marker species and thus, will not be apportioned properly.
- Carbon fractions that are not necessarily associated with specific compounds might yield different profiles for different source types. Unfortunately, at the present time there are insufficient data from source characterization studies to fully test the use of organic markers to determine the extent to which they are successful at quantifying source contributions.
- Relative contributions of local and long-range transport are difficult to distinguish. Source profiles are often similar for distant and nearby sources and thus, multiple techniques, including detailed observation-based analysis, must be used to address this question.
- An important point to note and a major limitation to PPSA is with the selection of sampling sites, which will alter the contribution percentages. For example, at traffic junctions such as Punjagutta and Chikkadpally, vehicular contribution is significantly high, and a station closer to the industrial estates in the north would have resulted in industrial sources dominating.

To gain insight into the relative importance of local and long-range sources, receptor models must be applied at various locations and times that are expected to influence various scales of modeling (e.g., nearby [<1 km from the monitor], neighborhood [1 to 5 km], urban [>10 km], regional [100 to 1000 km]). Conducting such an analysis clearly requires a well thought-out conceptual model. For example, the two key stations considered in this study (Punjagutta and Chikkadpally) are located within a 5-km radius, and both are dominated by vehicular emissions but still show traces of industrial sources among the results, a contribution of long-range transport. Comparison of source contribution estimates for short-term or long-term averages from the locations can be used to separate source contributions related to the different spatial scales. However, there has been very little work done on this issue and thus, new measurements and research are needed.

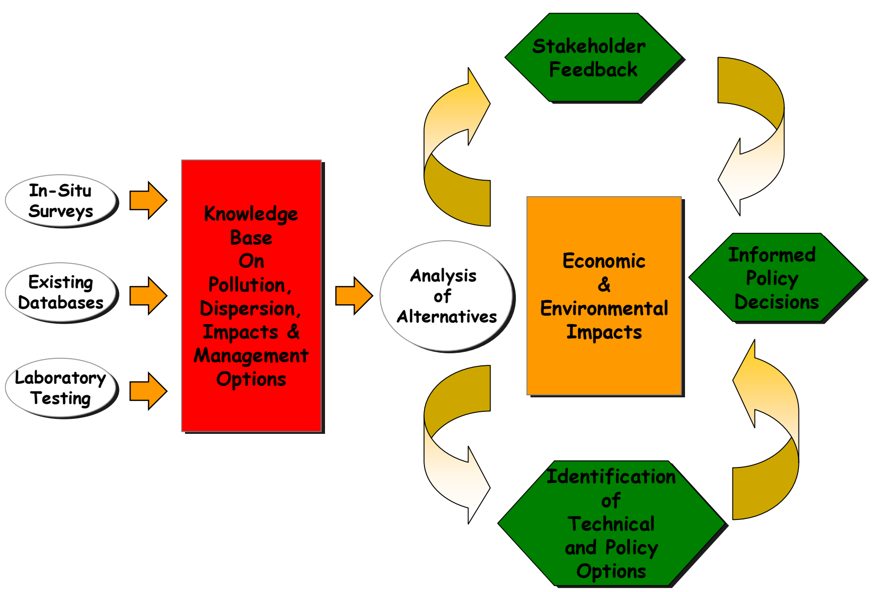
The experience from this exercise and the equipment should be utilized for further sites to enhance the robustness of these results.

Chapter

4. Emission Inventory Analysis for Hyderabad

In order to set priorities for urban air quality improvements, information is needed on sources and their contribution to the ambient levels of pollution. The purpose of source apportionment is to reduce the level of uncertainty in the estimates of the contribution sources (i.e., transportation, power, industry, residential, commercial, agricultural, construction, and natural). Given the complexity that accompanies estimating the contribution of these sources to ambient levels of pollution, it is important to consolidate the top down estimates with some bottom up calculations.

Figure 4.1: Steps to Emission Inventory Analysis



Developing an accurate emission inventory is a daunting challenge. Figure 4.1 presents various steps involved in developing an emission inventory using information from a number of sources.
A level of uncertainty will always be present, but experience has shown that the uncertainty can be reduced sufficiently to allow development of a cost-effective AQM program. Potential gaps include inaccurate knowledge of unexpected

sources, meteorological conditions, failure to adequately account for long-range transport of pollutants, and area sources such as trash burning. Also, in order to avoid cleanup expenses, polluters have incentives to hide the seriousness of their pollution emissions, which makes the estimation of emission factors and emissions inventory difficult.

4.1 Summary of Annual Emissions

A thorough and transparent bottom-up emission inventory of stationary and transportation combustion sources was compiled under IES Phase 1 by EPTRI, Hyderabad, India[11]. The emission inventory included both ambient air pollutants and GHGs for 2001. The results of the emission inventory and subsequent air quality modeling indicated that the primary source of PM_{10} emissions in Hyderabad is the transportation sector (~62 percent), with the industrial sector being the second largest source.

Following the source apportionment study in 2005-06, the emission inventory and analysis was updated for year 2006 to support the top-down estimates and source contributions. The methodology employed for this analysis is a simple calculation tool[12] using activity levels from domestic, industrial, and transport sectors, and emission factors from studies across India, where local specific information is not available. Analysis tables and figures presented in this section draw from the baselines established under Phase I and statistics updated for base year 2006. Table 4.1 presents a summary of total annual emissions for PM_{10}, SO_2, NO_x, and CO_2 for 2006 followed by percent contributions of various source categories in Figure 4.2.

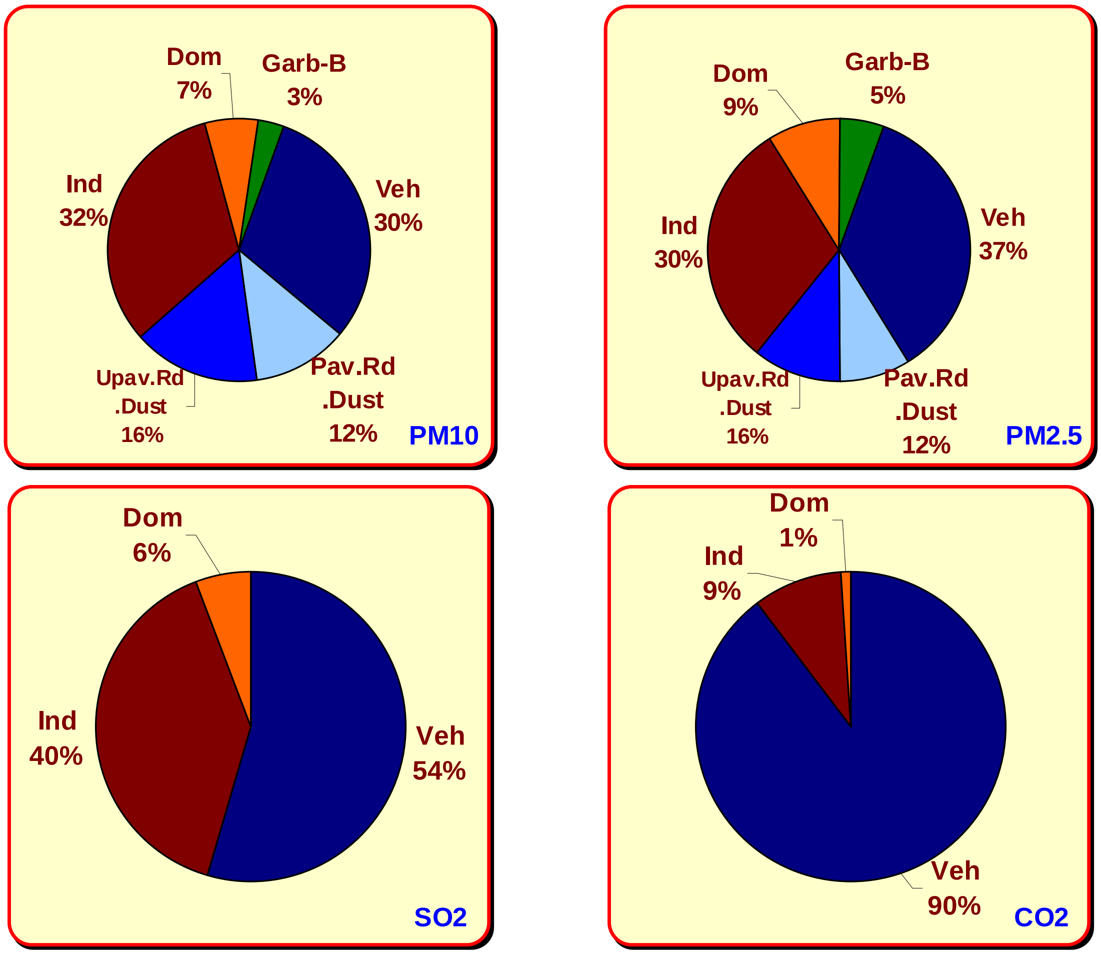
Table 4.1: Estimated Emission Inventory for 2006 (tons/year)

Category	PM_{10}	SO_2	NO_x	CO_2
Vehicular Activity	8,410	6,304	39,262	6,400,337
Paved Road Dust	3,272			
Unpaved Road Dust	4,279			
Industries	8,985	4,606	5,070	654,717
Domestic	1,845	667	545	83,485
Waste Burning	810			
Total	**27,599**	**11,577**	**44,877**	**7,138,538**

[11] Documents on analysis results and surveys are available at http://epa.gov/ies/india/documents.htm

[12] The simple interactive tool for better air quality (SIM-air) is available for download at www.sim-air.org, and the application for Hyderabad is available upon request via the IES Program.

Figure 4.2: Percent contribution of source sectors to annual emissions in 2006



Note: Dom = Domestic; Veh = Direct vehicular emissions; Pav.Rd.D = Paved road dust; Upav.Rd.D = Unpaved road dust; Ind = Industrial activity; Garb-B = Curb side waste burning and at landfill sites

The local PM, SO_2, and NO_x emissions are dominated by the direct and indirect contribution from the transportation sector. Direct annual PM emissions are estimated at ~30 percent. The indirect PM emissions due to resuspension of road dust are estimated at ~28 percent. For most of the city, residential areas (especially the central sections) utilize liquefied petroleum gas (LPG). However, parts of the city and some restaurants use coal and fuel wood and are known to contribute to outdoor and indoor air pollution.

For SO_2 emissions, its source is sulfur in the coal and diesel—diesel usage primarily by the heavy-duty vehicles and usage for generator sets in the industries. Total coal usage in the industries is on the rise. Although better controls for desulfurization are being proposed and are in use, the shear increase in fuel consumption and higher productivity in the industrial sector led to an increase in sulfur emissions. Diesel-based passenger cars are also on the rise; it is estimated that there is an equal split between gasoline and diesel usage in the city.

For CO_2, a major GHG gas, transportation accounts for 90 percent of the emissions, followed by industry. On average, it is estimated that ~600 new vehicles are being added to the in-use fleet.

It is important to note that these are estimates of emissions from various sources and cannot be directly compared to the source apportionment results presented in the previous chapter, as the latter represents the analysis based on ambient concentrations.

4.2 Industrial Emissions

For the industrial emissions inventory, the baselines were developed using the IES Phase 1 results along with updated information from industrial database developed by APPCB during its annual audit carried out in 2005. Within the city limits, there exists a large industrial sector covering metal and agricultural processing, paints, tanning, and pharmaceuticals.

Table 4.2: Estimated Industrial Emissions (in tons) by Fuels in 2006

Fuel (units)	Fuel Usage	PM_{10}	SO_2	NO_x	CO_2
Coal (tons)	307,811	6,926	3,078	2,367	317,384
Wood (tons)	37,194	107	-	-	3,690
Husk (tons)	124,381	970	-	-	14,067
Coke (tons)	30,360	171	167	310	92,546
NG (tons)	-	-	-	-	-
LPG (tons)	150,380	-	-	1	450
Diesel (lts)	26,872,029	274	218	2,054	72,554
Furnace Oil (lts)	49,685,679	537	1,143	338	154,026
Total		**8,985**	**4,606**	**5,070**	**654,717**

Tables 4.2 and 4.3 present emissions by fuel type and a summary of industrial layout in the city. In 2001, a total of ~650 industries were registered under HUDA jurisdiction. According to the audit in 2005, the total number was reduced to ~390. During this time, some of the industries were closed, relocated, or merged with others within the IDAs.

Table 4.3: Estimated Industrial Emissions (in tons) by IDA in 2006

IDA in HUDA	# of Industries	PM_{10}	SO_2	NO_x	CO_2
Amberpet	2	5	5	8	2,495
Autonagar	1	0	0	1	52
Azamabad	9	2,334	1,049	818	114,368
Aziznagar	1	12	9	88	3,104
Bahadurpura	4	450	4	1	6,970
Balanagar	22	177	89	87	10,167
Chandrayanagutta	5	906	384	287	41,290
Chandulbaradari	2	47	20	16	2,153
Chevella	1	3	1	1	119
ECIL Post	1	115	119	716	30,775
Gachiboli	1	2	4	1	475
Gaganpahad	32	484	272	305	88,827
Gandhinagar	3	13	10	12	1,327
Ghatkesar	8	79	5	18	1,910
Hayathnagar	17	212	206	90	30,429
Ibrahimpatnam	1	1	0	0	38
Jeedimetla	60	1,635	932	670	106,118
Kandukur	1	36	16	14	1,711
Kattedan	27	217	57	45	7,476
Kukatpally	5	58	27	20	2,824
Maheswaram	2	21	3	8	687
Malkajgiri	1	121	54	41	5,532
Mallapur	16	50	21	44	3,140
Medchal	26	253	154	173	22,112
Miralam Tank	1	40	17	13	1,800
Moinabad	2	9	18	5	2,395
Moulali	8	166	130	138	17,321
Nacharam	24	267	220	159	34,634
Quthubullapur	20	182	161	153	21,980
Rajendranagar	5	30	26	12	3,342
Sananthnagar	3	22	48	14	6,439
Shameerpet	1	6	3	16	715
Shamshabad	8	189	94	64	10,446
Shamsheergunj	1	52	23	18	2,371
Shankarpalli	2	43	19	15	1,976
Uppal	12	100	75	60	9,624
Pathancheru	50	569	290	823	50,505
Pashamailaram	7	80	41	115	7,071
Total		**8,985**	**4,606**	**5,070**	**654,717**

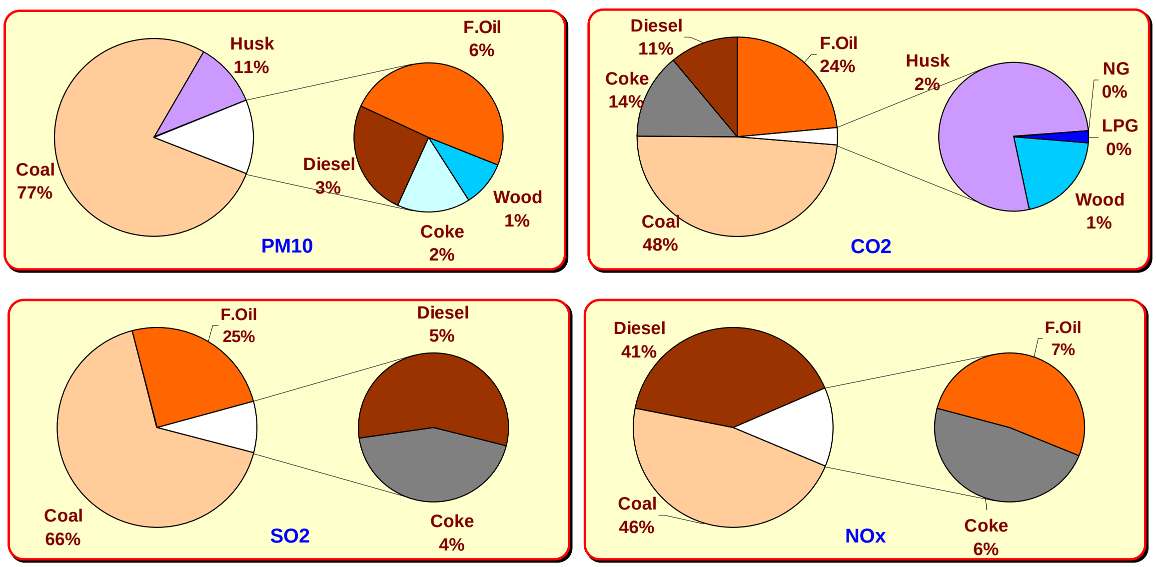
The methodology employed in this study is simple. For industrial or household fuel consumption, ***Emissions = Activity * Emission Factor***; where, ***Emissions*** is tons of pollutant emitted per year; ***Activity*** is the amount of fuel used (e.g., tons of coal burned per year); and ***Emission Factor*** is tons of pollutant emitted per ton of fuel burned. A summary of the emission factors is presented in Table

4.4. For industrial or household sources with controls, ***Emissions = Activity * Emission Factor * (1 – Efficiency)***; where, ***Efficiency*** is the efficiency of the control technology, such as scrubbers and ESP in the power plants.

Table 4.4 Summary of the Emission Factors for Industrial Sources[13]

	CO_2	N_20	CH_4	PM_{10}	SO2
	Tons eCO2 per ton			kg/ton	%
CNG	2.7500	0.0000	0.0000	0.0600	0.0000
DIESEL	0.0027	0.0000	0.0000	0.0102	0.0081
LFO	0.0022	0.0000	0.0000	0.0108	0.0330
HFO	0.0031	0.0000	0.0000	0.0108	0.0330
LPG	2.9800	0.0069	0.0030	0.0600	0.0000
COAL	0.9920	0.0043	0.0348	18.0000	0.0100
COKE	2.9400	0.0118	0.0965	2.1000	0.0055
AGRI Waste	0.0000	0.0186	0.0945	7.8000	0.0000
BAGASSE	0.0000	0.0025	0.0504	7.8000	0.0000
Fuel Wood	0.0000	0.0047	0.0945	2.8800	0.0000

Figure 4.3: Percent Contribution by Fuel to Industrial Emissions in 2006



For example, for PM emissions: ***Emissions = Coal Use * Ash Content * (1 – Ash Retention)***. This methodology results in total TSP emissions. For the calculations, 20 percent of the ash generated is assumed to escape from the boilers.

[13] Based on the industrial analysis from IES Phase1 – http://www.epa.gov/ies

For sulfur, the similar equation is ***Emissions = Coal Use * Sulfur Content;*** since no sulfur controls measures are in place, it is assumed that all of the sulfur is emitted in the form of SO_2. One percent sulfur content by weight is assumed for coal used.

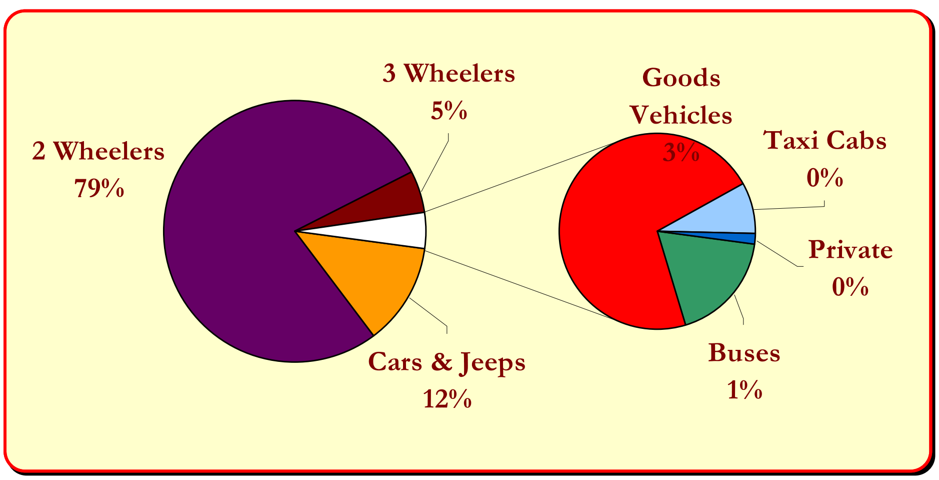
For NO_x, an emission factor of 750 kg per TJ (10^{12} joules) is used. This number is obtained as an average from a variety of sources, such as the SEI Emissions Inventory study[14], GAINS[15], and U.S. EPA[16]. The calorific value of coal used is set at 2700 kcal.

Of the emission inventory presented, coal dominates the local and GHG emissions. The largest IDAs in HUDA (presented in Figure 2.2) with the highest emissions are Jeedimetla, Patancheru, Medchal, Nacharam, and Azamabad.

4.3 Vehicular Emissions

The transportation sector is one of the fastest growing sectors in Hyderabad, owing to the growing population and economy linked to the expanding information technology (IT) industry. Public transport usage is among the largest in the country, but privately owned passenger cars are growing to take a share of the vehicle kilometers traveled (VKTs) (see Figure 4.4).

Figure 4.4: Share of In-Use Vehicles in 2006



It is estimated that in 2006, a total 1.8 million registered vehicles were on the road, with current estimates putting the number as high as 2 million for 2007—a 10 percent increase in one year. The city has also one of the best laid out

[14] http://www.sei.se/index.php?section=atmospheric&page=projdesc&projdescpage=99928
[15] GAINS - http://www.iiasa.ac.at/rains/gains/index.html
[16] U.S. EPA AP-42 - http://www.epa.gov/ttn/chief/ap42/

internal road systems connected with flyovers on the main corridors to ease the traffic congestion. Many of the important roads are three-lane on either side.

Of the total, two-wheelers dominate with a 79 percent share, with a mix of two-stroke and four-stroke. This is followed by passenger cars at ~230,000, a category with highest growth rate. Vehicular statistics used for emission inventory analysis are summarized in Table 4.5. Statistics are based on surveys conducted by APPCB staff and approximated for this analysis.

A mix of three-wheelers with a fuel mix ranging from gasoline, diesel, LPG, and duel-fuel operates in the city. Some of the older generations are still two-stroke in nature with higher total hydrocarbon (THC) and PM emission rates. A low share of three-seater and seven-seater auto rickshaws also exists, covering the public transport system. Moreover, the size, number, and aggressive driving style of auto-rickshaw operators exacerbates congestion and hinders the speed and reliability of other transportation modes, particularly buses.

Table 4.5: Vehicular Statistics Utilized for Emissions Estimation in 2006

Category	Number	VKT per day	Avg Wt.	Paved Road Traffic
	Units	km	Tons	of Total
Cars & Jeeps	229,114	60	3.16	70%
Buses	14,436	240	13.2	80%
Goods Vehicles	57,377	100	10	50%
Taxi Cabs	6,723	250	3.24	90%
2 Wheelers	1,431,139	40	0.3	80%
3 Wheelers	80,016	200	1	70%
Private	1,343	100	5	70%

The public transportation system operates ~15,000 point-to-point buses that connect important places within the city, with a very good frequency. This includes a variety of bus categories—from ordinary, stopping at all the stations, and metro buses, which stop at designated stations. This enables passengers to commute quickly between any two places within the city and is considered the largest state-owned public transport system in the world. However, due to the burgeoning number of personal vehicles, the city is beginning to face problems, such as reduced operating speeds due to congestion and higher pollution levels from diesel operated vehicles.

Hyderabad city also operates a light rail transportation system known as the Multi Modal Transport System (MMTS) covering 27 stations and a rail length of 43 km. An estimated 70,000 commuters use this service everyday.

For the vehicular emission inventory, the fundamental equation utilized is ***Emissions* = *Vehicles* * *VKT* * *Emission Factor***; where, ***Emissions*** is tons of pollutant emitted per year; ***Vehicles*** is the number of vehicles in-use; ***Emission***

Factor is grams of pollutant emitted per km; and ***VKT*** is the vehicle kilometers traveled per year.

Table 4.6: Average Emission Factors (in gm/km) for Indian Vehicles

Vehicle Type	CO	HC	NOx	CO2	PM
Scooter 2-St Post 2005 >80cc	0.16	0.86	0.02	38.5	0.057
Scooter 4-St Post 2005 >100cc	0.40	0.15	0.25	42.1	0.015
MC 2-St Pre 2000 >80cc	2.96	2.44	0.05	24.2	-
MC 4-St Post 2000 <100cc	1.65	0.61	0.27	25.0	0.035
MC 4-St Post 2000 >100cc	1.48	0.50	0.54	24.8	-
MC 4-St Post 2005 >200cc	0.72	0.52	0.15	45.6	0.013
3W 2-St Post 2000 <200cc	1.37	2.53	0.20	62.4	0.045
3W 2-St Post 2005 <200cc	1.15	1.63	0.16	71.5	0.043
3W 4-St Post 2000 <200cc	1.97	0.84	0.40	62.7	0.030
3W 4-St Post 2005 <200cc	2.29	0.77	0.53	73.8	0.015
3W Diesel Post 2000 <500cc	2.09	0.16	0.69	173.9	0.347
3W Diesel Post 2005 <500cc	0.41	0.14	0.51	131.6	0.091
3W CNG-4S Post 2000 <200cc	1.00	0.26	0.50	77.7	0.015
3W CNG-2S Post 2000 <200cc	0.69	2.06	0.19	57.7	0.118
3W LPG-2S Post 2000 <200cc	1.70	1.03	0.04	68.2	0.130
P.Car Petrol Pre 2000 <1000cc	4.83	0.58	0.65	98.6	0.019
P.Car Petrol Post 2000 <1000cc	1.30	0.24	0.20	126.4	0.004
P.Car Petrol Post 2000 >1400cc	2.74	0.19	0.21	142.9	0.006
P.Car Petrol Post 2005 >1400cc	0.84	0.12	0.09	172.9	0.002
P.Car Diesel Pre 2000 <1600cc	0.87	0.22	0.45	129.1	0.145
P.Car Diesel Post 2000 <1600cc	0.72	0.14	0.84	156.8	0.190
P.Car Diesel Post 2005 <1600cc	0.06	0.08	0.28	148.8	0.015
P.Car Diesel Pre 2000 >1600cc	0.66	0.25	0.61	166.1	0.180
P.Car CNG Pre 2000 <1000cc	0.85	0.79	0.53	149.4	0.001
P.Car CNG Post 2000 <1000cc	0.06	0.46	0.74	143.5	0.006
P.Car LPG Pre 2000 >1000cc	6.78	0.85	0.50	130.9	0.001
P.Car LPG Post 2000 >1400cc	2.72	0.23	0.20	140.0	0.002

A summary of emission factors published by CPCB[17] for Indian vehicles is tabulated in Table 4.6. These emission factors are utilized in conjunction with available databases from other transport models, such as the ICLEI database for Indian Vehicles in HEAT[18] and for similar categories and controls in other developing countries, especially the older vehicles. For cars and SUVs, emission rates are averaged between vehicles 5 years old and new ones. For buses and trucks, emission factors of vehicles older than 8 years are assumed. Main sources of information on emission factors are HEAT, the SEI emission inventory, and U.S. EPA (old vehicles). The numbers obtained from these

[17] "*Emission Factor development for Indian Vehicles*". CPCB, New Delhi, India. Published August 2007.

[18] Harmonized Emissions Analysis Tool - www.iclei.org/heat

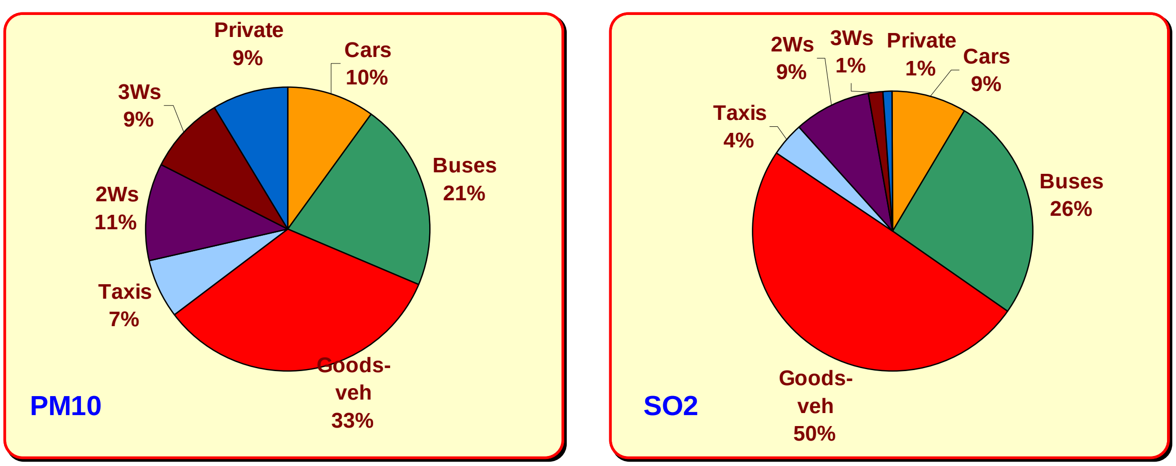
databases for old vehicles were adjusted for some wear and tear, assuming an emission factor deterioration rate of 3 percent.

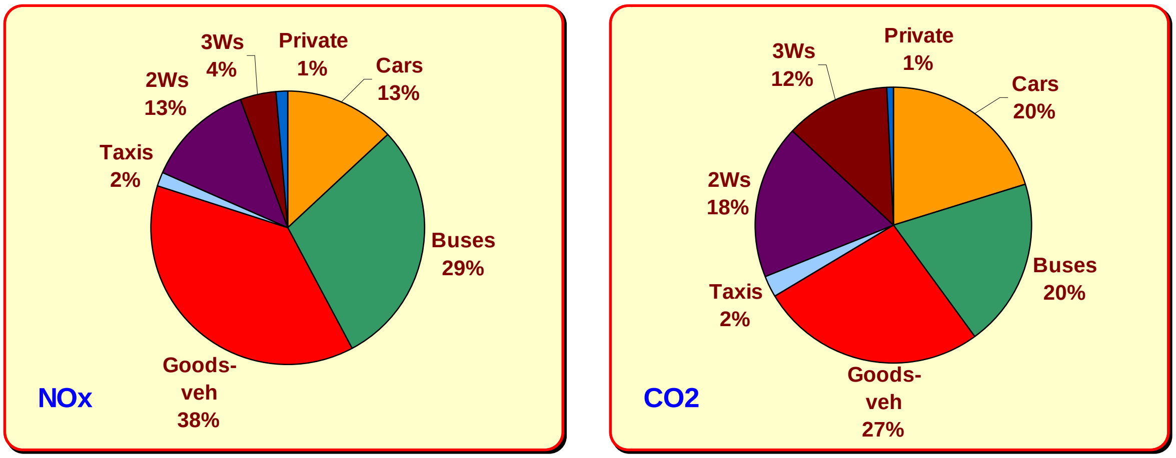
Table 4.7: Estimated Emissions From In-Use Vehicles in 2006 (tons/year)

Category	Number	PM_{10}	SO_2	NO_x	CO_2
Cars & Jeeps	229,114	841	545	5,105	1,295,859
Buses	14,436	1,804	1,640	11,478	1,257,071
Goods Vehicles	57,377	2,798	3,141	14,834	1,697,065
Taxi Cabs	6,723	569	239	613	153,368
2 Wheelers	1,431,139	926	571	5,041	1,170,099
3 Wheelers	80,016	749	94	1,187	630,260
Private	1,343	724	74	515	56,378
Total	**1,820,147**	**8,410**	**6,304**	**38,772**	**6,260,099**

Total annual emissions due to vehicular traffic is estimated at 8,400 tons for PM_{10} (~30 percent of annual total) and ~6.26 million tons for CO_2 in 2006. Table 4.7 presents a summary of the in-use vehicular emissions, and Figure 4.6 presents the percent contribution of various categories. For PM_{10}, emissions are dominated by diesel-based goods vehicles and public transport buses that travel long distances within the city. Although two-wheelers dominate the vehicle fleet, because most of them operate on gasoline, their share of PM emissions is limited to ~10 percent. In case goods vehicles, the average age of vehicles is also high, making them the worst polluters on the road. Similarly for SO_2, diesel-based goods vehicles and public transport buses contribute ~75 percent of the total. On the other hand, for CO_2 emissions, load is equally divided between two-wheelers, private cars, public transport buses, and goods vehicles. In the last five years, the share of two-wheelers and private cars doubled and is only expected to increase in the next five years.

Figure 4.5: Estimated Percent Contribution of Vehicles in 2006

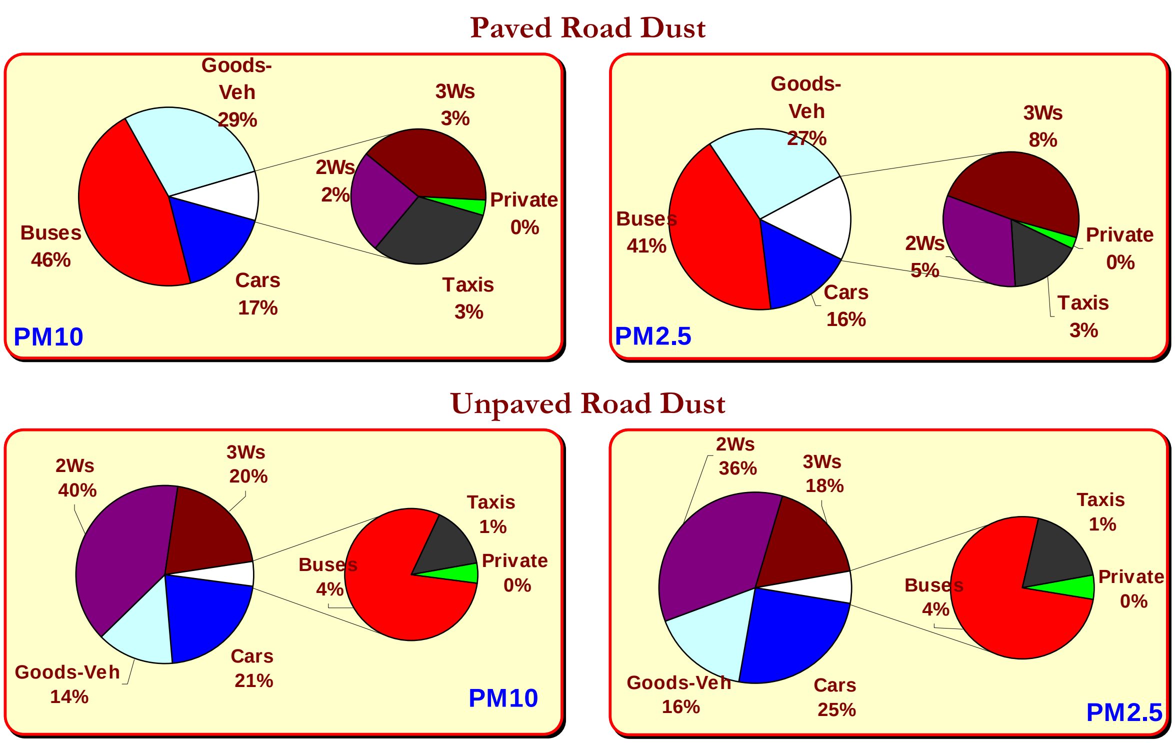




4.4 Vehicular Road Dust Emissions

The emissions from nontraditional sources, such as fugitive dust from transport and nontransport activities, are calculated using empirical equations based on U.S. EPA's AP-42 manual. These empirical equations are developed for applications in U.S. cities, but are useful in *providing an estimated guidance* where no such studies are done, such as in Hyderabad, India.

Figure 4.6: Percent Contribution of Vehicles to Road Dust in 2006



Being empirical, these estimates should be analyzed with some caution. As an example, the PM_{10} fugitive dust from paved roads is calculated using the formula,

$$E = [4.6 * (\frac{sL}{2})^{0.65} * (\frac{W}{3})^{1.5}) - C] * (1 - \frac{P}{4N})$$

where ***E*** = fugitive dust emissions factor in gm/VKT; ***sL*** is the silt loading on the roads in gm/sq.m; ***W*** is the average weight of vehicles on the road in tons; ***C*** is a wear and tear factor in units of ***E***; ***P*** is the number of precipitation days; and ***N*** is the total number of days for calculation.

Emissions were calculated based on vehicular information received from the transport department (see Table 4.5). For Hyderabad, a silt loading of 100 gm/sq.m is assumed, which is typical for dry and dusty areas. Similar methodologies are applied for unpaved road dust.

From the empirical equation, the PM resuspension rate not only depends on the dust loading, but also on the number of vehicles on the road, VKT, and weight of the vehicles. The large, heavy-duty vehicles tend to produce more resuspended dust compared to the two-wheelers, mainly because of their body size and weight, followed by their VKT. Figure 4.6 presents percent contribution of various vehicular categories to paved and unpaved road dust in Hyderabad. This is an inventory; a 40 percent split is assumed between $PM_{2.5}$ and PM_{10}.

4.5 Garbage/Biomass Burning

Burning of household and industrial waste on roadsides, in backyards, or at landfills is prohibited. However, there are regular incidences of burning along roads—following road sweeping or in residential corridors where all the waste accumulates. Emissions of PM and other criteria pollutants from garbage burning are hard to quantify and are accompanied by large uncertainty.

A recent study conducted by APPCB suggests that toxic chemicals released during garbage burning include NO_x, SO_2, volatile organic chemicals, and polycyclic aromatic hydrocarbons such as carcinogenic benzene and xylene. Burning plastic and treated wood also release heavy metals and toxic chemicals such as dioxin.

There is one large landfill operated by the HUDA municipality near Autonagar, and according to APPCB, ~5 percent of the trash collected gets burned at the landfills, and more in the residential areas. Usually, the in-situ trash burning is more prevalent in areas outside of the municipality (blue boundary in Figure 2.2). For Hyderabad, garbage burning is estimated to account for 810 tons of PM_{10} annually (~3 percent of the annual total).

4.6 Limitations to Emissions Estimation

Although quality assurance plans are in place to ensure best results, there are uncertainties and limitations to consider when evaluating the emission inventory. Some limitations are common throughout the world.

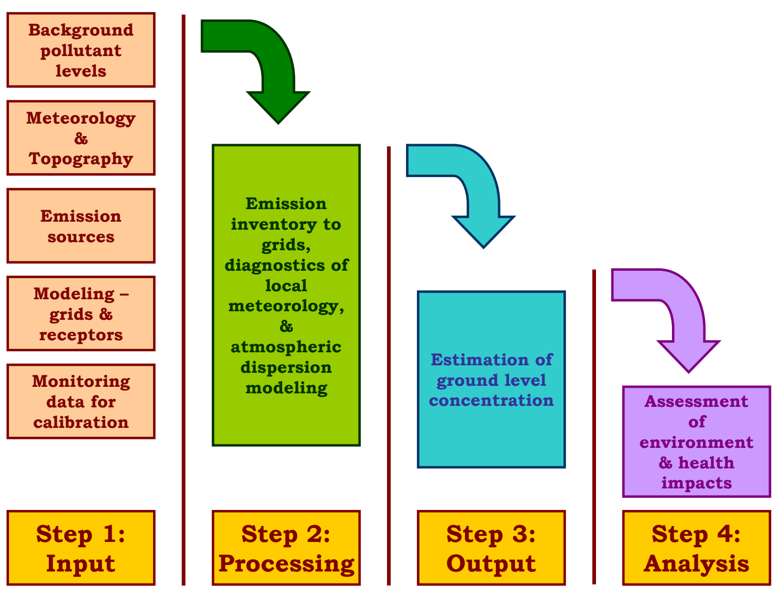
- In all inventories not all pollutants are included because some emission factors are missing or emission factors are of poor quality, resulting in unrepresentative emission estimates (for example in garbage burning).
- This analysis primarily focuses on PM emissions for their direct health impact and GHG emissions for combined benefits of local and global impacts.
- Primary concern in the point source inventory is lack of source-specific emission information from individual facilities. The combustion and chemical processing differ from one facility to the other. However, an average composition data from these facilities was utilized to estimate emissions.
- For transport sector emissions, the analysis is based on average emission factors, due to lack of emission factor testing facilities in the city and lack of financial support to undertake any such study at this juncture. However, emission factors for a similar mix of vehicles were utilized from studies conducted by CPCB and other agencies.
- Activity levels for some area sources and road traffic were allocated from registered totals, which might not represent the actual local activities.

Chapter

5. Air Pollution and Health Impacts Analysis

The process of air pollution analysis contains four stages, depicted in Figure 5.1, starting with data input and processing. The accuracy and uncertainty of each stage must be known and evaluated to ensure a reliable assessment of the significance of any potential adverse effects. The main objective of this exercise is to analyze the impact of air pollution on human health from a bottom-up perspective and to consolidate the results with the source apportionment study for further review.

Figure 5.1: Schematics of Air Pollution Modeling



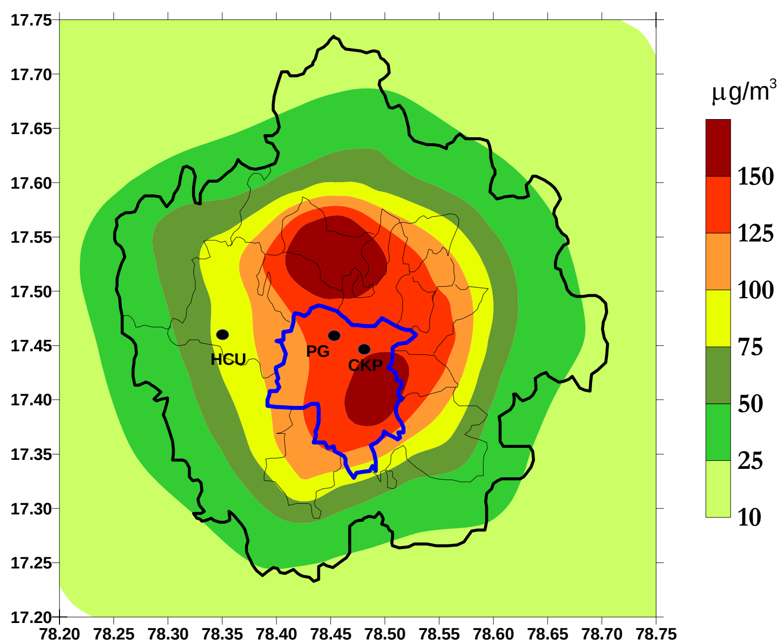
The emission inventory presented in Chapter 4 is gridded to the HUDA region, and ambient levels of PM are evaluated for compliance, contribution of various sources to ambient levels, and human health impacts overlaid on the population grid.

5.1 Air Pollution Modeling Results

For the Hyderabad study, we utilized the ATMOS dispersion model[19]. Meteorological data was obtained from NCEP Reanalysis fields for the grid containing Hyderabad. All the simulations were conducted using meteorological data for 2006[20].

Figure 5.2 presents the modeled annual average concentrations of PM_{10} along with the three monitoring sites from the source apportionment study. A background concentration of 12μg/m^3 is assumed for this modeling exercise based on the monitoring data from the sites designated as background sites—HCU and KBRM park (see Figure 2.3).

Figure 5.2: Modeled Annual Average PM_{10} Concentrations in 2006



Note: HCU = Hyderabad Central University; PG = Punjagutta; CKP = Chikkadpally; Blue line represents Municipal Corporation of Hyderabad (MCH) boundary; Thick black line represents HUDA boundary

The estimated annual average includes concentrations of primary PM emissions and secondary PM due to SO_2 and NO_x emissions in the form of sulfates and nitrates. In the HUDA region, on average, secondary PM contributes 20 to 40

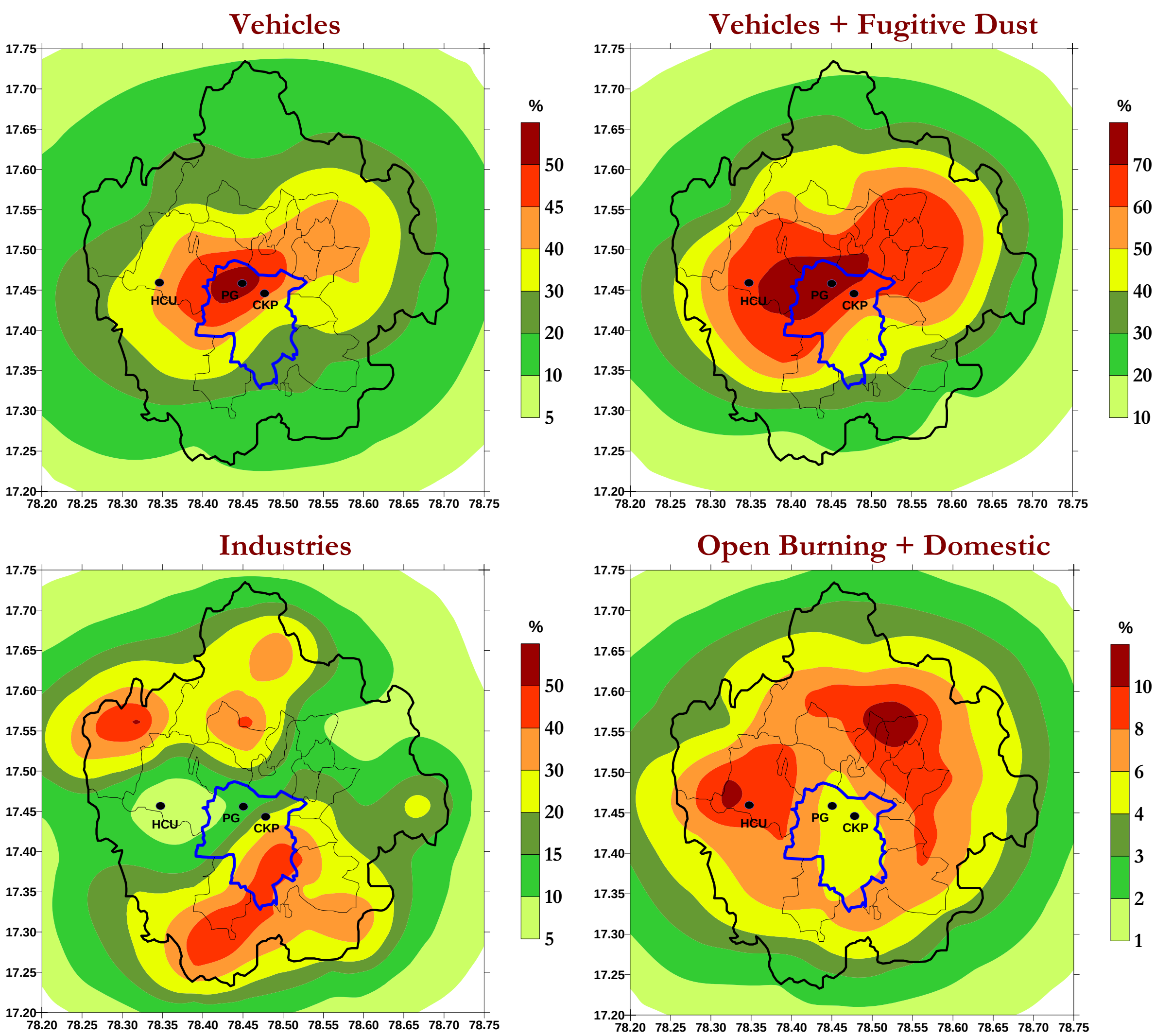
[19] A lagrangian puff transport model modified for urban applications. Details of the model and a manual are available here http://www.cgrer.uiowa.edu/ATMOS/atmos-urbat-linux. Model reference - **Calori et al, 1999**. "*An urban trajectory model for sulfur in Asian megacities: model concepts and preliminary application.*" Atmospheric Environment 33, pp.3109–3117.

[20] A detailed analysis of the meteorological conditions in Hyderabad is presented in "Particulate Pollution Source Apportionment for Hyderabad," which is available for download on the IES Web site.

percent of total PM_{10}, and more to the $PM_{2.5}$ fraction. Because of varying dispersion characteristics, primary PM concentrations are calculated in two bins—one less than fine fraction ($PM_{2.5}$) and one coarse fraction ($PM_{10} - PM_{2.5}$). All the secondary sulfate and nitrate concentrations were assigned to the $PM_{2.5}$ fraction.

The estimated annual average concentrations were calibrated against the measurements for year 2006. The urban points (first four) averaged 120 µg/m^3, and the background sites in the outer ring averaged 50 µg/m^3. On a daily basis, the urban points at times averaged over 200 µg/m^3.

Figure 5.3: Modeled Percent Contribution of Sectors to Annual PM_{10} in 2006



The highest concentrations in Figure 5.2 represent the areas with highest industrial density. The three blue points represent the monitoring sites for the source apportionment study. From the monitoring data presented in Tables 2.1 through 2.3; monitoring data from the source apportionment period presented in Table 3.2 and Figure 3.3; and the modeled PM_{10} concentrations, it is evident that ambient concentrations for the HUDA urban area are frequently above the national ambient guidelines.

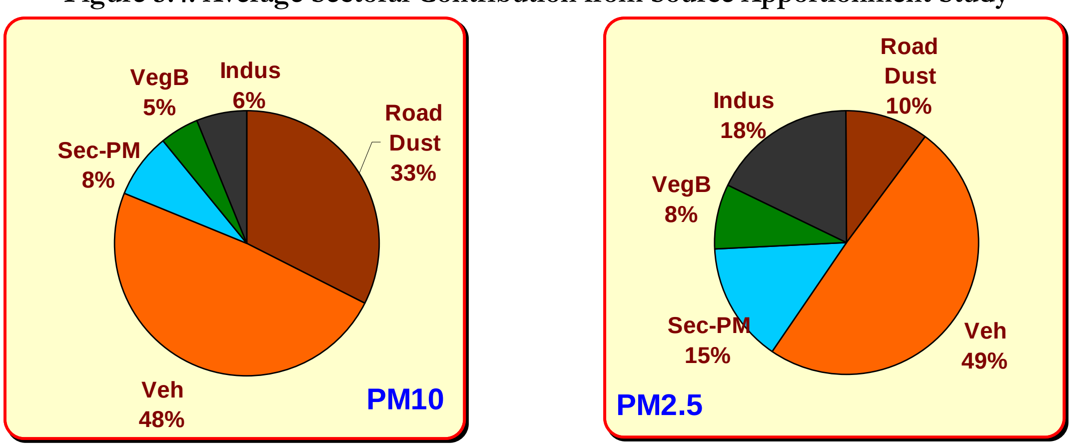
The ambient concentrations were also calculated at the individual sectoral level. Figure 5.3 presents percent contributions for individual sectors to annual average concentrations[21]. For this exercise, emissions from individual sectors were analyzed separately for PM, SO_2, and NO_x to segregate the results as much as possible.

The pollution due to vehicular activity dominates the ground-level concentrations. Vehicular emissions and resuspension dust are emitted at ground level, and their dispersion characteristics are limited to the local surroundings. In the case of industrial sources, due to stack heights of 20 to 50 meters, the tendency for long-range transport of pollutants is higher, and this is represented in a more scattered plot for industrial contribution in Figure 5.3. In the municipality region where the population density is highest, the contributions range between 20 to 50 percent for vehicular, 40 to 70 percent when combined with road dust, and 10 to 30 percent for industrial sources. Domestic and garbage burning sources ranged between 3 to 10 percent and were concentrated outside of the municipal boundaries. The city landfill is located to the southeast of the municipal boundary.

5.2 Consolidation with Source Apportionment Results

One of the objectives of the source apportionment study presented in Chapter 3 is to verify and, if possible, update the emission inventory developed under this study.

Figure 5.4: Average Sectoral Contribution from Source Apportionment Study



[21] Geographical distribution of industries in the HUDA area was made available by APPCB.

Note: Figures are averaged over three sampling sites and three phases. From Figures 3.5 through 3.7, Coal and Cement are included under industry; ammonium sulfate and nitrate are included under Secondary PM.

Figure 5.4 summarizes the source apportionment results from Chapter 3. Results represent an average of all three stations and three sampling periods. Note that the modeling exercise in the last section is based on an annual average.

Table 5.1 presents a comparison of a range of modeled concentrations to estimated source apportionment results for the three sampling stations. The modeled (M) results indicate the color range over the monitoring site in Figure 5.3, and the source apportionment (SA) results indicate the range of results from CMB modeling for each monitoring site.

Table 5.1: Comparison of Top-Down and Bottom-Up Analysis Results (%)

Location	Vehicles		Veh + Road Dust		Industries		OWB+Dom	
	SA	**M**	**SA**	**M**	**SA**	**M**	**SA**	**M**
Punjagutta	54 ± 10	50 - 55	81 ± 10	70 - 75	13 ± 10	10 – 15	5 ± 10	4-6
Chikkadpally	45 ± 10	45 - 50	80 ± 10	60 - 70	15 ± 10	20 – 30	4 ± 10	4-6
HCU	43 ± 10	30 - 40	80 ± 10	60 - 70	16 ± 10	5 – 10	5 ± 10	8-10

Note: Top-Down is source apportionment (SA) and Bottom-Up is modeled (M)

The analysis presented in Table 5.1 is for qualitative comparison only, with averaged level of uncertainties for CMB modeling. This should not be considered the final or only comparison of the results for the following reasons.

During the source apportionment CMB modeling:

- No distinction is made between diesel and fuel oil utilized by vehicles and industries. The entire diesel portion is assigned to the vehicular contribution, thus overpredicting the vehicular and underpredicting the industrial contribution.
- Similarly, coal combustion between industries and domestic sectors are not distinguished.
- All types of dust—road and soil—are grouped together, thus overpredicting the road dust contribution.
- Two of the sampling points are urban with most vehicular activity. An average of these points will be biased toward vehicular contributions, as seen in Table 5.1.
- Source profiles used for CMB modeling were based on similar studies conducted elsewhere, which puts an unknown uncertainty on the results. Having said that, the source profiles for similar technologies and similar fuel characteristics present comparable results.

- Air pollution modeling results are annual average values, where as the CMB modeling results are averaged over the three sampling months and three sampling sites.

Given the uncertainties and deficiencies in emission estimation, air pollution modeling, and source apportionment, qualitatively and partly quantitatively, the results present a close comparison between the two methodologies; further emphasizing the need for such consolidated and integrated studies for urban centers to identify the potential for reducing local pollutants.

5.3 Health Impact Evaluation

Evaluation of health effects is a challenging exercise as it not only depends on the local emissions and ambient levels, but also pollution sources, when the pollution occurs (i.e., exposure times and levels), and aggregation of multipollutant effects (e.g., acidity due to SO_2 emissions; PM and ozone on human health; acidity and ozone formation capacity of NO_x emissions). Also, the relationship between air pollution levels and health impacts is non-linear, so the incremental effects of changes in pollutant concentrations are higher in highly polluted areas. Studies in the past have not been able to clearly establish this relationship, and it is an on-going study[22].

Table 5.2: Average Dose Response Functions for Health Endpoints

Health Endpoint	Dose Response Function (effects/1μg/m³ change/per capita)
Mortality	0.000014
Adult Chronic Bronchitis	0.000040
Child Acute Bronchitis	0.000544
Respiratory Hospital .Admission	0.000012
Cardiac Hospital Admission	0.000005
Emergency Room Visit	0.000235
Asthma Attacks	0.002900
Restricted Activity Days	0.038280
Respiratory Symptom Days	0.183000

Studies in India have shown that acute respiratory infection in children under five is the largest single disease category in the country, accounting for about 13 percent of the national burden of disease[23]—children living in households using solid fuels have two to three times more risk of ARI than unexposed children[24]. In China, air pollution from fuel combustion is estimated to cause 218,000 premature deaths (equivalent to 2.9 million life-years lost), 2 million new cases of chronic bronchitis, 1.9 billion additional restricted activity days,

[22] Health Effects Institute (HEI), Boston, USA. http://www.healtheffects.org

[23] Comparative Quantification of Health Risks - http://www.who.int/publications/cra/en/

[24] Smith, et al., 1999. "Indoor air pollution." Pollution Management in Focus, the World Bank, Washington, DC, USA.

and nearly 6 billion additional cases of respiratory symptoms[25]. The culprit pollutant in both China and India is believed to be fine PM. While estimates of health impacts are effective in raising overall concern about air quality, they do not specifically answer the question of the sources of fine PM, nor what measures should be taken to reduce the impacts associated with exposure.

For this study, health impacts were evaluated based on the population distribution and dose response functions[26] presented in Table 5.2. For 2006, grid-based estimates for annual average concentrations were evaluated against an annual PM_{10} WHO standard of 80 μg/m^3 as a threshold value for occurrence of heath impacts.

Based on dose-response functions, health impacts derived for each grid were calculated using the equation

$$d(POP_{ij}) = \beta * A_i * POP_{ij} * (C_{ij} - C_{target})$$

where, ***d(POP$_{ij}$)*** represents the population exposed to concentrations in excess of target levels or business as usual (BAU) scenario levels at the receptor cell (i, j); ***β*** is the slope of the dose-response function for the health endpoint to the change in concentration or deposition of a pollutant; ***A_i*** = incidence rate of health endpoint; ***POP_{ij}*** = population exposed and susceptible to air pollution at the receptor cell; ***C_{ij}*** = concentration or deposition of the pollutant at the receptor cell (i, j); ***C_{target}*** = target level or air quality guideline concentration or deposition of the pollutant.

Table 5.3: Estimation of Health Impacts Based on Modeling Results for 2006

Health Endpoint	Number of Incurred Cases
Mortality	2,790
Adult Chronic Bronchitis	4,814
Child Acute Bronchitis	43,365
Respiratory Hospital .Admission	1,136
Cardiac Hospital Admission	966

[25] Lvovsky, et al. 2000. "Environmental Costs of Fossil Fuels: A Rapid Assessment Method with Application to Six Cities." Environment Department Paper No. 78, the World Bank, Washington, DC, USA; and Bell, et al., 2006. "The avoidable health effects of air pollution in three Latin American cities: Santiago, São Paulo, and Mexico City." Environmental Research, 100, March 2006, 431-440.

[26] Reference material for dose response functions and case studies. (1) WHO, 1999, Air Quality Guidelines, http://www.who.int/peh/air/Airqualitygd.htm; (2) Ostro, et al., 1994, 'Estimating the Health Effects from Air Pollutants: A Method With an Application to Jakarta.' World Bank Policy Research Working Paper #1301; (3) Xu, et al., 1994, 'Air Pollution and Daily Mortality in Residential Areas of Beijing, China.' Archives of Environmental Health, 49, pp. 216-222; (4) SAES, 2000, 'Shanghai Energy Option and Health Impact.' Report prepared by Shanghai Academy of Environmental Sciences and Shanghai Medical University (5) "Cost of Pollution in China", East and Pacific Region, the World Bank, Washington DC - http://go.worldbank.org/FFCJVBTP40.

Emergency Room Visit	46,912
Asthma Attacks	577,936
Restricted Activity Days	7,628,756
Respiratory Symptom Days	36,469,756

Table 5.3 presents the results of the health impact analysis. Besides mortality, morbidity end points, such as adult and child chronic bronchitis, respiratory hospital admissions, cardiac hospital admissions, emergency room visits, asthma attacks, restricted activity days, and respiratory symptom days, were also considered.

5.4 Health Impact Valuation

A critical part of the assessment is the valuation of impacts. The willingness to pay (WTP) methodology presented in Lvovsky et al., 2000, was utilized to present monetized health impacts and can be useful in the cost-benefit analysis of interventions. Table 5.4 presents estimated WTP rates for individual health end points in India.

It is important to note these values are derived based on epidemiological studies conducted in various countries and extrapolated using GDP elasticity. Following the health impacts evaluation, the valuation of health impacts is conducted using the following equation.

$$d(V_{ij}) = d(POP_{ij}) * V$$

where, $\boldsymbol{d(POP_{ij})}$ represents exposure as a function of population (w.r.t. concentrations in excess of target levels or the BAU scenario levels at the receptor cell (i, j)); $\boldsymbol{V}$ represents the unit economic value of the effect based on WTP, medical treatment costs, remuneration for working day (see Table 5.4); and $\boldsymbol{d(V_{ij})}$ represents costs or benefits that are likely to result from an increase or decrease in air pollutant concentrations.

Table 5.4: Average Willingness to Pay for Health Endpoints

Health Endpoint	Willingness to Pay (US $) per Effect[27]
Mortality	50,400.00
Adult Chronic Bronchitis	3,031.00
Child Acute Bronchitis	1,010.00
Respiratory Hospital .Admission	131.00
Cardiac Hospital Admission	9,333.00

[27] These willingness to pay values are averaged and adjusted based on local GDP. A GDP of US$1000 is assumed for India. Reference case study is US mortality and morbidity health costs for the listed health endpoints. This is a conservative estimate and needs local studies to corroborate.

Emergency Room Visit	4.00
Asthma Attacks	2.00
Restricted Activity Days	2.00
Respiratory Symptom Days	1.00

Valuation of health impacts or any other endpoint, such as loss in agricultural yield due to acid rain or ozone exposure, loss of visibility due to smog formation, or economic loss of structural damage due to corrosion, is an uncertain process and is very debatable in nature. A large number of studies have been conducted and or are being carried out (HEI) to quantify these impacts and to better associate the impacts in monetary terms. In case of Hyderabad, for the current baseline scenario, the total health costs incurred for 2006 are estimated at $260 million US or ~Rs.990 crores[28]. Of the total, morbidity impacts account for 46 percent. Health impacts were calculated using a 80 μg/m^3 threshold for each grid point.

[28] At currency exchange rate of 1USD = Rs.38.00

Chapter

6. Emissions Forecast and Pollution Analysis

Using growth and control strategy, projections accounted for as many of the important variables that affect future year (2010 to 2020) air pollutant and GHG emissions as possible. The trend analysis provides an insight into the future emission levels and local air quality. These projections will provide a basis for developing control strategies for an air pollution action plan and conducting benefit analyses for future years.

6.1 Emission Forecasts

Under a BAU scenario, an emissions forecast was conducted for 2010, 2015, and 2020, using the emission inventory presented in Chapter 4. Figure 6.1 and Table 6.1 present estimated emissions for PM_{10}, $PM_{2.5}$, SO_2, and NO_x for 2010, 2015, 2020.

Figure 6.1: Projected Annual Emission Estimates Through 2020

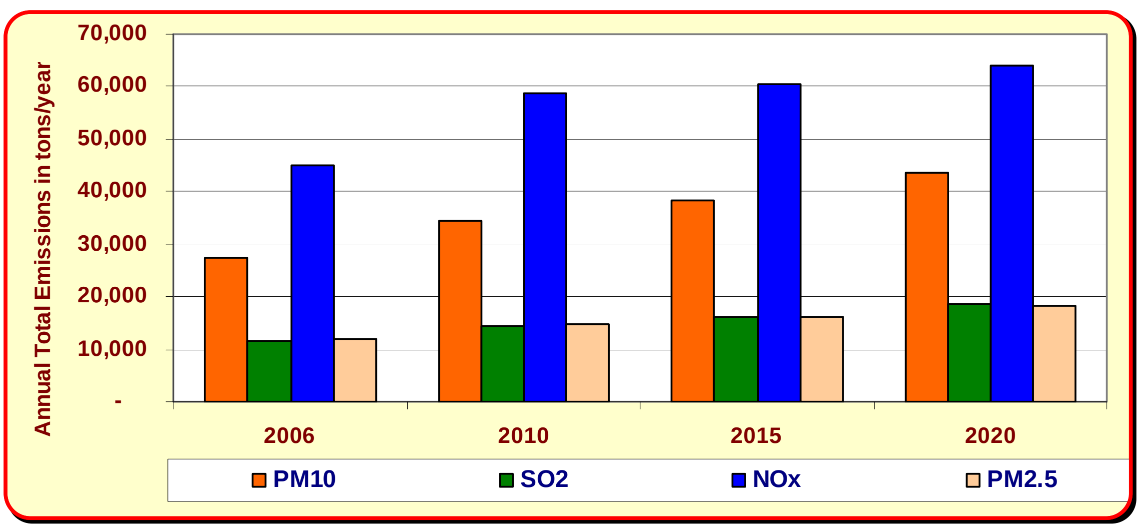
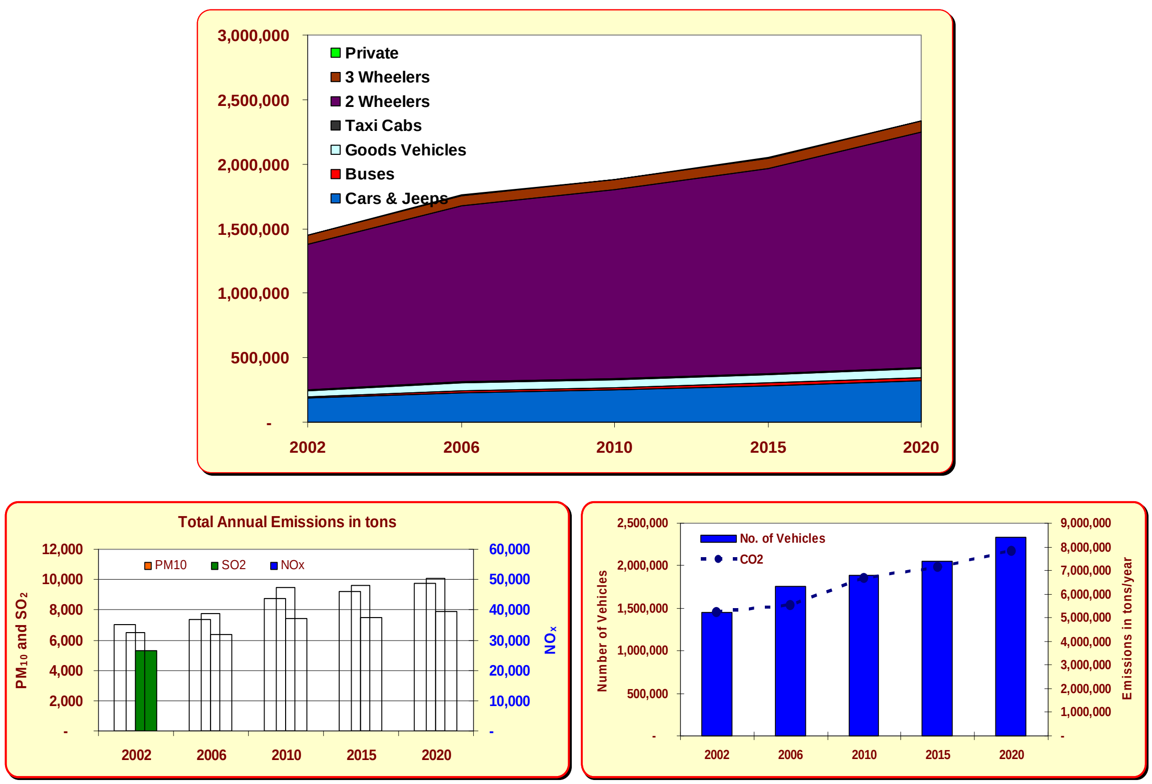


Table 6.1: Projected Emission Estimates for Hyderabad from 2010 to 2020 (tons/year)

	PM_{10}	SO_2	NO_x	CO_2	$PM_{2.5}$
2006	29,599	11,577	44,877	7,138,538	11,380
2010	34,620	14,520	58,638	9,352,590	14,688
2015	38,341	16,201	60,331	9,638,503	16,250
2020	43,550	18,670	63,694	10,310,520	18,412

It is important to note that these are BAU scenarios assuming no new controls for most of the source categories, except for changes in emission norms for newer vehicles. The real time growth could be even lower than what is projected in the BAU scenario.

Figure 6.2: Projected Annual Vehicular Emission Estimates Through 2020



For industrial emissions, an average growth rate of 3 percent in fuel consumption is assumed. For the transport sector (presented in Figure 6.3), varying levels of growth rates were assumed based on the current trends. For example, the two-stroke motorcycles are expected to decrease or be replaced by the four-stroke vehicles. The overall emission growth rate is expected to flatten after 2010 for most of the sectors, with inherent development of newer technologies.

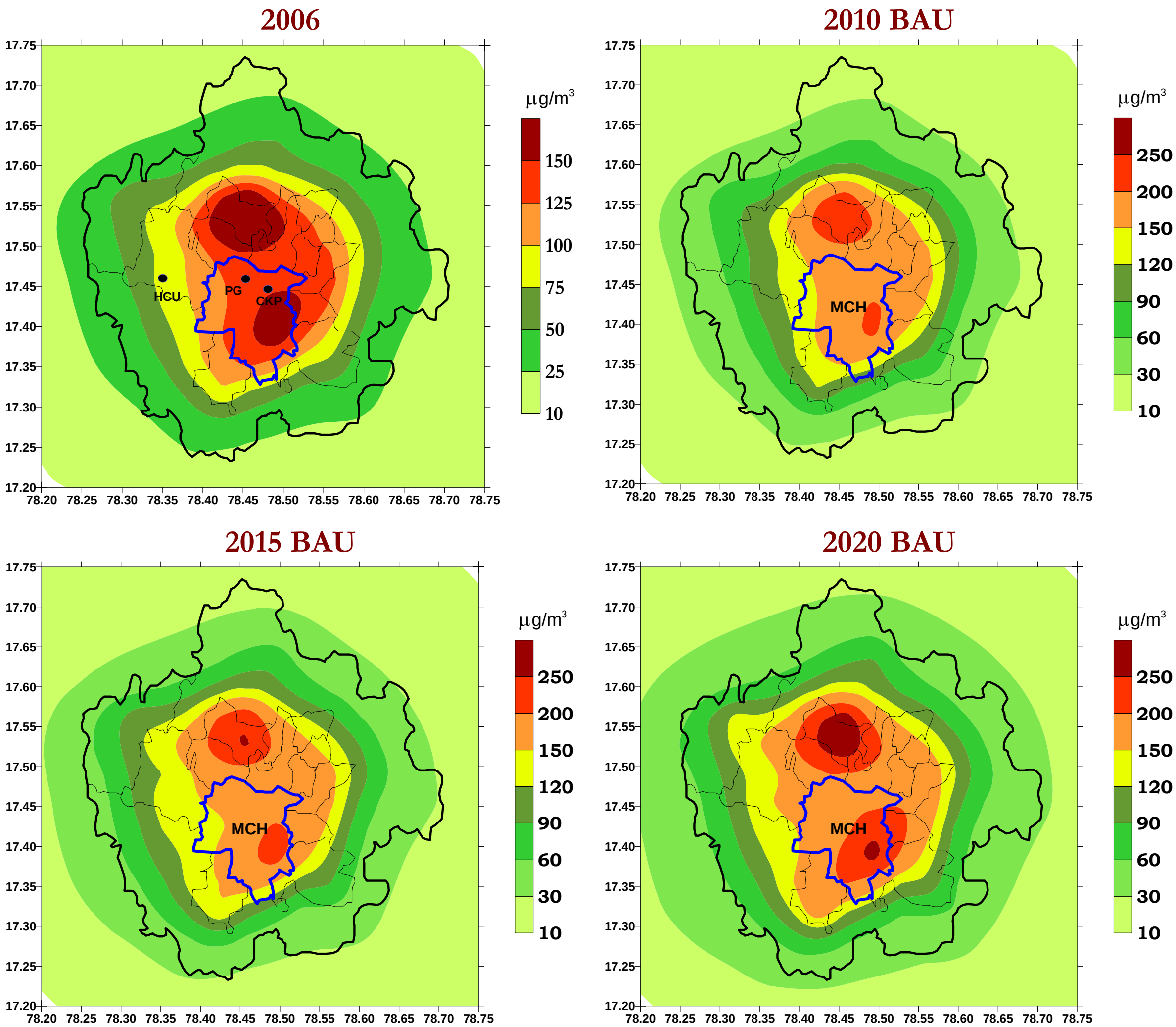
The largest change is expected to come from the transport sector. Among the vehicle categories, passenger cars are expected to experience the largest growth in the coming decade—~10 percent per year through 2015 and decreasing thereafter—due to introduction of intense rail public transport. Growth of the total vehicular fleet is presented in the first panel of Figure 6.2. The demand for transportation is a derived demand; it is not demanded for its own sake, but rather for the things it enables people to do (such as get to work, take leisure trips, and move goods). Given the land-use patterns and constraints on availability of land for roads, the number of vehicles on the road could flatten in the next decade. Irrespective of the introduction of new technologies and higher emission standards, an increase in emissions is expected because of an increase in consumption levels. Estimates for 2002 are from IES Phase 1 analysis results.

The key driver behind growth transport sector emissions is income. Associated transport sector emissions increase both because more travel is being undertaken, and because as people get richer, they want to travel using more carbon-intensive modes (e.g., switching from bus to train, from train to car, from small car to large car). And this is also evident from the increasing contribution to GHG emissions (lower righthand panel of Figure 6.2). By 2020, under current trends, GHG emissions are estimated to increase ~50 percent to ~10 million eCO_2 tons/year.

6.2 Air Pollution and Impacts Forecasts

Similar to the air pollution modeling and health impact analysis for base year 2006, dispersion modeling was conducted for 2010, 2015, and 2020. Annual average concentrations of PM_{10} are presented in Figure 6.3. All the simulations were conducted with base meteorology from 2006.

Figure 6.3: Modeled Annual Average PM_{10} From 2010 to 2020 Under BAU



In Hyderabad, under current trends, air pollution continues to have a significant negative impact on public health, even in areas that are away from the main industrial estates and transportation corridors. The assessment carried out for the review estimates that future PM levels will far exceed the guidelines. Through 2010, increases are expected in and around the MCH area and outside of MCH for 2020, with more pronounced expansions planned in the later years; estimated increases in ambient concentrations ranged between 40 percent and 90 percent compared to 2006 levels. It is important to note these are simulated and assumed growth rates for the future impact assessment.

Table 6.2: Estimation of Health Impacts Based on Modeling Results for 2006

Health Endpoint	Number of Incurred Cases		
	2010	**2015**	**2020**
Mortality	4,553	5,048	6,347
Adult Chronic Bronchitis	7,856	8,710	10,951
Child Acute Bronchitis	70,766	78,460	98,650
Respiratory Hospital .Admission	1,854	2,055	2,584
Cardiac Hospital Admission	1,626	1,803	2,267
Emergency Room Visit	76,555	84,878	106,720
Asthma Attacks	943,118	1,045,647	1,314,733
Restricted Activity Days	12,449,157	13,802,539	17,354,479
Respiratory Symptom Days	59,513,997	65,983,926	82,964,203

Irrespective of the percent changes, the annual average concentrations are already exceeding the national and global standards for public health and, if unchecked, pose the greatest environmental challenge. Estimated annual average concentrations measured a minimum of 150 $\mu g/m^3$ in the MCH area. Table 6.2 presents results of the health impact analysis for 2010 to 2020 for mortality and morbidity endpoints under BAU.

Using the data presented in Table 5.4, valuation of these health impacts was conducted for the estimated health impacts presented in Table 6.2. In case of the Hyderabad study, for a BAU scenario, total health costs incurred range from ~$426 million US or ~Rs.1,622 crores for 2010 to ~$473 million US or ~Rs.1,798 crores for 2015 to ~$594 million US or ~Rs.2,260 crores for 2020.

The development of a diversified industrial structure, based on a combination of large and small-scale industries, along with growing demand for energy services, number of vehicles on the road, and the population has led to growing incidence of air degradation.

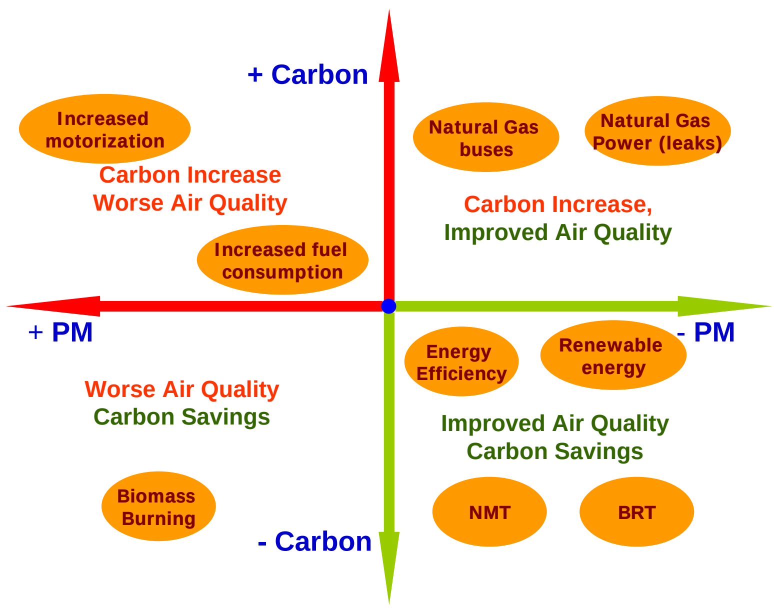
The largest changes in the ambient levels and increases in the health impacts are expected in the short term (by 2010), mainly because of the current trends in the growth of the vehicular population (~10 percent a year) and the construction activities adding to the fugitive dust on roads and in the air. After 2010, the rise in the number of health impacts flattens (compared to 2006) due to the spread of activities to areas outside of MCH and in-migration.

Chapter

7. City Action Plan and Co-Benefits Analysis

In many ways, local authorities are required to pursue measures that improve air quality, besides checking for compliance and regulatory purposes. The importance of climate change as an environmental issue of global significance has increased enormously in the past few years. Decision-makers preparing an action plan should bear in mind the synergies between air quality and climate change and the added benefits of an integrated approach.

Figure 7.1: Co-Benefits of Various Control Measures



Source: Dr. Cornie Huizenga, Executive Director, CAI-Asia, Manila, Philippines

A co-benefits approach as outlined in Figure 1.1 is increasingly becoming a starting point for discussing integrated programs benefiting climate change and air quality alike. Figure 7.1 depicts a scenario where the co-benefits can aide decision-making over a variety of control measures. For example, policies designed to reduce the impact of transportation on air quality by tackling congestion and encouraging a shift to public transport, walking, and cycling should also reduce CO_2 emissions. Measures to improve energy efficiency and cut energy demand also reduce air pollutants and GHG emissions during electricity generation. In developing countries, this approach is being recognized as a practical and effective tool in technical, policy, economic, and institutional perspectives.

In this study, the benefits of air quality improvement (local) are measured in terms of reduced health effects (presented in the previous chapters), while the global benefits are measured in terms of GHG emission reductions. In literature, there are discussions of the health consequences of climate change itself (a direct consequence of GHG emissions), or of the extent to which these effects are likely to be mitigated with implementation of integrated programs. However, in this study, under co-benefits, health impacts are evaluated from an air quality perspective only.

7.1 Control Measures for Air Pollution and GHG Emissions

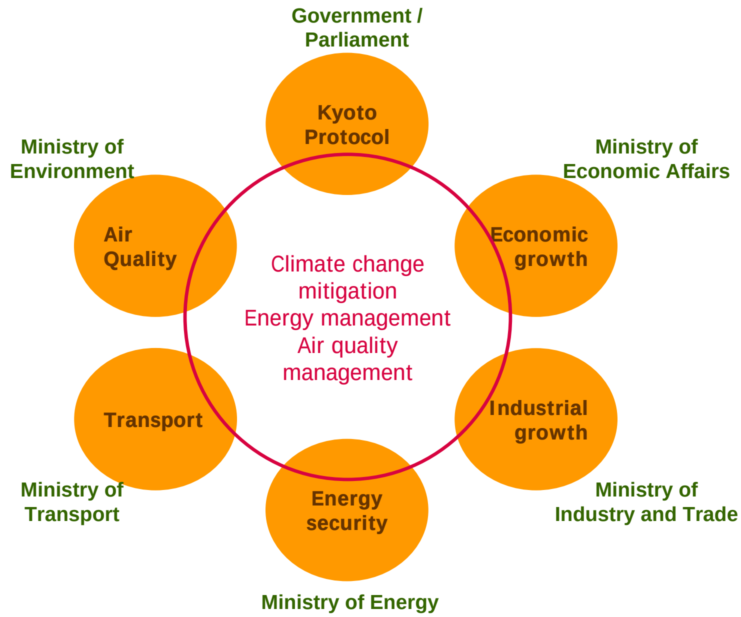
There is no single measure that on its own will realize the full attainment of the air quality objectives, so packages of measures will need to be deployed. Table 7.1 presents an array of pollution measures divided into policy, technical, economic, and institutional categories. Measures can be technological (e.g., integrating pollution abatement technologies into road vehicles and industrial processes), as well as designed to change behaviors (e.g., smarter choices, traffic management measures, incentives for cleaner vehicles and road pricing).

Table 7.1: Categorized Array of Control Measures for Decision-makers

Policy & Legal	Technical	Economic	Institutional
Urban planning	Cleaner technologies	Taxes	Monitoring
Industrial zoning	End of pipe control devices	Pricing	Emission standards
Residential zoning		Charges (congestion)	Fuel standards
Energy efficiency	Fuel improvements	Fines for violations	Inspections
Traffic management	Cleaner production	Subsidies	Enforcement
Public transport		Tradable permits	Maintenance
Non-motorized transport			Capacity building
			Knowledge base
Environmental law			Awareness
Compliance			

Operationalizing the idea of co-benefits will require specifying which institutional arrangements will be employed and which incentive structures will be established to reap said benefits. Unfortunately, integrating among the multistakeholder network (presented in Figure 7.2) in any city that responds to these questions presents yet another challenge. This challenge arises, in part, from the fact that environmental goals are interdisciplinary with varying levels of impacts. Some measures require international agreement, for examples the measures targeting the GHG emissions, while the others can be more determined at the national or local level.

Figure 7.2: Policy and Institutional Integration to Achieve Co-Benefits



Source: Dr. Cornie Huizenga, Executive Director, CAI-Asia, Manila, Philippines

Road transport is a key source of many air pollutants, particularly in urban areas. There are two main trends in the transportation sector working in opposite directions: new vehicles are becoming individually cleaner in response to emission standards legislation, but total VKTs are increasing[29]. Promising areas of improved co-benefits are (a) introduction of an effective inspection and maintenance program for all types of vehicles, starting with passenger cars and motorcycles; (b) improving the quality of fuel by decreasing the sulfur content of diesel to reduce SO_2 emissions—a precursor to secondary PM; (c) introducing stricter regulations against fuel efficiency of the vehicles on the supply side of road transport; (d) promoting public transportation and increasing access to public transportation via infrastructure development for bus rapid transport and metro rail systems; and lastly, (e) promoting nonmotorized transport in the cities by building walkways and bikeways.

Among the fuel substitution options, LPG and CNG appear to be a relatively wide-scale method of reducing local pollution in the transport sector, provided availability of the necessary infrastructure to supply and administer the fuels on a larger scale. LPG is primarily suited to cars and small petrol vehicles and is currently in use after ~50 percent of the petrol-based three-wheelers are retrofitted to use LPG. The CNG is suited for light-duty trucks and heavy-duty buses in the public transportation sector, but the supply chain is limited in Hyderabad. Currently five public transport buses are in the testing phase with

[29] Society of Indian Automobile Manufacturers, http://www.siamindia.com

a supply of three tankers of CNG every day from filling stations in Vijayawada. With these alternative fuels, the cost benefits are mainly applicable where high mileages are the norm, as seen in Figure 7.1.

Table 7.2: Local and Global: Synergies and Conflicts for the Transportation Sector

Local Intervention	Synergy with Global Concerns	Conflicts with Global Concerns
Introducing CNG or other alternative liquid fuels	CNG has been introduced for air quality improvement in cities such as Delhi, Beijing, and Bangkok. CNG or propane vehicles emit less PM than conventional vehicles.	Leakages of un-burned CNG may increase eCO_2 emissions in heavy-duty engines.
Introducing low-sulfur diesel	High-quality and low sulfur diesel fuel may help reduce CO_2 emissions if additional CO_2 emissions at refineries do not offset such gains.	
Promoting electric and hybrid vehicles	Electric vehicles have no tailpipe emissions, including all air pollutants and CO_2.	Electric and hybrid vehicles have compromised-driving performance and are expensive. The CO_2 benefits depend on the fuel mix of electricity generation. Only LCA can provide a clear picture.
Introducing emissions/fuel efficiency standards for vehicles	Standards help to reduce local air pollutants and CO_2 emissions per vehicle-km (by type or size).	If distance traveled by individual vehicles increases or if people switch to vehicles with bigger engines, the total eCO_2 will increase, even though the individual standards are met.
Promoting mass transport and discouraging use of private cars	By improving overall energy performance; reducing congestion; and reducing fuel use, this measure reduces CO_2 emissions.	Inefficiency in operation of mass transport systems tends to reduce their occupancy and promote private modes of transport; the gain may be less than expected.
Introducing reformulated gasoline	Reformulated gasoline can help reduce smog, VOCs, and toxic air pollutant emissions.	Reformulated gasoline compromises with fuel economy nominally by 1 or 2 percent; therefore, CO_2 might increase.
Biofuels (ethanol blended gasoline or biodiesel)	Biofuels can reduce eCO_2 emissions.	Some conflicting studies have reported an increase in eCO_2 emissions in their life -ycle assessments.
Inspection and Maintenance systems; changing driving conditions; driver behavioral training	This measure improves fuel efficiency of the vehicle; thereby reducing CO_2 emissions.	Rebound effects need to be monitored
Congestion	Reduces congestion and idling;	However, the exact impact on

pricing and traffic management	discourages car use; results in fuel savings;.	eCO_2 emissions is unknown.

Source: Dr. Dhakal, Executive Director, Tsukuba, Japan. Presentation at Better Air Quality 2006, Jogjakarta, Indonesia

Hybrid vehicles are still in the beta stage, with dual-fuel cars and three-wheelers, and some electric bikes. The proportional energy savings (higher mpg) is truly green. Optimistically, perhaps the hybrid cars will start an alternative approach to transportation, increasingly using efficient electrical motors, as seen among a small fraction of motorcycles.

Among the nonroad transport interventions, fugitive dust due to entrainment is a major source of air pollution. This intervention is for 100 percent local benefit and a major source. In the past, city officials have piloted heavy machinery sweepers followed by wet sweeping, operated during the night, to control the dust loading on roads.

Congestion pricing[30] in urban centers is among the first economic measures and has been successfully implemented in London, United Kingdom and Stockholm, Sweden. Congestion pricing is the practice of charging motorists to use a roadway, bridge, or tunnel during periods of the heaviest use. Its purpose is to reduce automobile use during periods of peak congestion, thereby easing traffic and encouraging commuters to walk, bike, or take mass transit as an alternative. It is important that the city provides the alternative transportation modes before implementing this measure. On average in London, congestion pricing is expected to reduce 20 to 30 percent of the downtown passenger car traffic.

In the industrial sector, the energy efficiency of fuel combustion[31], especially coal and diesel, is vital. In Hyderabad, there are no thermal power generation units, but the industrial sector and to some extent the domestic sector uses substantial amount of diesel and bunker fuel for alternative power using generator sets. With energy demand in the industrial sector growing a minimum of 3 percent per year, and the mix of fuels used switching from wood to coal to oil, strict implementation of energy efficiency will have a significant influence on local and global emission levels.

Industrial zoning and land-use planning are also keys to reducing the exposure levels[32]. With the city expanding in all four directions, the human exposure to higher pollution levels is expected to increase, as evident in Chapter 6, and it is important that authorities introduce clear interventions to move the densely packed industries away from the populated areas. And while urban planning,

[30] More on road pricing on Wikipedia @ http://en.wikipedia.org/wiki/Road_pricing

[31] The "Energy Efficiency Guide for Industry in Asia" provides a 6-step methodology to improve industrial energy efficiency; case studies with technical information on different energy equipment, training materials, and other tools are available @ www.energyefficiencyasia.org for assistance.

[32] Confederation of Indian Industry, http://www.ciionline.org

new commercial and residential establishments should consider implications of zoning on vehicle traffic and pedestrian movement.

In the industrial sector, interventions to substitute unconventional fuels (listed in Figure 4.3) with traditional fuels that can be controlled better are encouraged. Some of the manufacturing sectors, such as tanning and bricks (outside of the city limits), are known to burn unconventional field residues, adding to unaccounted local and global emissions. This can also be averted by introducing stricter emission standards for small- and medium-scale enterprises, followed by periodic inspections and enforcement.

For larger industrial plants using coal and oil for primary energy demand, efficient methods for flue gas desulfurization and dust capture are recommended.

With real estate booming in and outside the city, the share of local brick and cement industries to the manufacturing sector and local and global pollution is high. Green building[33] projects are increasing in Indian residential complexes, exhibition centers, hospitals, educational institutions, laboratories, information technology parks, airports, government buildings, and corporate offices. The move is opening up new challenges and opportunities for everyone from architects, builders, material, and equipment suppliers to real estate developers, property operators, and individual owners.

Table 7.3: Summary of Possible Measures for Hyderabad City Action Plan

Transportation Sector	Industrial Sector
• Encourage use of alternative transit—public transit, bus rapid transport, metro rail, van or car pooling, cycling, and walking (NMT) • Procure high fuel-efficiency vehicles • Dedicate lanes for transit/high occupancy vehicles • Improve scheduling efficiency of buses • Improve inspection and maintenance • Introduce alternative fuels • Fund infrastructure improvements • Adjust public transit fares for economic incentives • Pilot congestion pricing to decrease VKT • Introduce regular and effective sweeping programs to control fugitive dust	• Introduce urban planning via industrial and residential zoning • Mandate state-of-the-art pollution control technologies for dust capture and sequestration of SO_2 and NO_x emissions • Introduce new legislation for industrial energy efficiency • Promote energy conservation programs • Offer economic incentives or tradable permits for energy efficiency improvements, fuel switching (solar), heat recovery/co-generation (CDM). • Mandate audits (inspections) for industrial energy services for periodic assessments • Recommend process changes and energy efficiency improvements

[33] Indian Green Building Council, http://www.igbc.in/igbc/home.jsp

Waste Sector

- Introduce public awareness for home composting and distribute compost bins
- Introduce landfill methane collection program from waste to energy
- Scale-up and centralize recycling program from residential, commercial, and industrial zones
- Establish of centers for reusing salvageable goods
- Recover food waste for composting or bioenergy
- Offer incentives for purchasing recycled goods

Street Lighting

- Replace existing lighting and traffic signals with energy efficient solar, CFLs, or LEDs
- Reduce energy use by decreasing hours of operation and/or number of lights

Buildings (Domestic, Commercial, and Government)

- Promote household energy conservation via Energy Star program; public awareness
- Conduct regular energy audits to monitor use and efficiency improvements (CFLs)
- Perform comprehensive retrofit of existing buildings, parks, stadiums, markets, etc.
- Require energy efficiency standards for renovations and new constructions
- Introduce in-situ PV and solar thermal systems for energy and water heating
- Encourage rooftop gardens and greening of buildings for cooling purposes

Among the uncertain and unaccounted sources, the area sources of pollution, except for construction, are the least regulated. Area sources include open burning of waste, biomass and agricultural residue; resuspended road dust; construction; and household cooking and eating.

In the domestic sector, the municipal residential area is supplied with LPG. However, the poor in the slum areas, along the construction sites (the most in the last five years), and in part, some restaurants, still use conventional fuels, such as coal, and unconventional fuels, such as biomass and agricultural waste, which is closely related to social behavior. As part of the urban planning process, more regulated supplies are required to control this source of emissions. In households, efficient lighting and energy-efficient appliances need promotion[34].

In domestic and, to some extent, industrial sectors, the share of renewable energy[35] in the form of wind and solar power is slowly increasing. This, however, has brought about the need for technology innovation to lower costs, and it requires skilled manpower, especially in the developing nations where technology advancement is limited.

One of the serious measures that needs immediate attention is biomass waste burning at landfills, along roadsides, and in residential areas. It is a common site in the fall to see leaves swept into piles and lit on fire, along with other

[34] Bureau of Energy Efficiency, Government of India, http://www.bee-india.nic.in
[35] Indian Renewable Energy Development Agency Limited, http://www.iredaltd.com

rubbish at residential curbsides. This burning emits unprecedented amounts of PM and other carcinogenic emissions. A complete ban of this activity is a must. With the introduction of CDM methodologies, waste-to-energy programs either by incineration or methane capture are gaining ground over traditional energy sources[36].

Lastly, among the non-measures, an important aspect of policy planning is knowledge-based management. In order to make informed choices among the bewildering array of options discussed above, decision-makers need to be able to analyze these options from an environmental, economic, social, political, and economic viewpoint. This approach is effective in bringing together interdisciplinary stakeholders and collecting knowledge from a large pool of decision-makers and end users. All of this requires flexible analysis frameworks to evaluate options as they emerge, which, in turn, need substantial quantities of relevant information on various aspects of emissions, air quality, and characteristics of management options. The study presented in this report and similar studies under the IES Program are such examples and, as part of the decision-making, the city should further improve its knowledge-based management so it can make informed decisions.

7.2 Proposed Pollution Control Action Plan by APPCB

As part of APPCB's report to the Burelal committee of the Government of India, a number of control options were outlined for air pollution reduction in Hyderabad. The Environmental Pollution (Prevention & Control) Authority (EPCA)[37] has identified four key areas that have the potential to engineer a fundamental transition. Suggested actions include:

- Gaseous fuel programs, both CNG and LPG, to leapfrog from current polluting diesel to cleaner fuel, particularly in grossly polluting segments like public transport and three-wheelers.
- Public transport and transport demand management to reduce the demand for growth of private motorization and reduce emissions.
- Vehicle inspection program for onroad vehicles to combat pollution from large fleets of existing vehicles.
- Management of transit traffic and phasing out of old vehicles to reduce the burden of pollutants in the city.

The action includes the following decisions[38]:

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[36] Ministry of New and Renewable Energy, Government of India, http://mnes.nic.in

[37] Environmental Pollution (Prevention & Control) Authority (EPCA), is part of the Burelal committee for air pollution control in India, was constituted by the Central Government on January 29, 1998, with Central Pollution Control Board of India providing all the technical and secretarial support in carrying out its functions.

[38] http://www.hyderabadgreens.org/automobile.html

- To expedite the supply of CNG/LPG for subsequent conversion and consumption of vehicles. Out of 68,840 three-wheelers in Hyderabad, a total of 29,346 have been converted to LPG-based vehicles. The remaining conversion is expected to finish in 2009-10.
- Currently, 2,836 buses are operated by Andhra Pradesh State Road Transport Corporation in the city. It is estimated that there are ~7 million commuters daily, of which 42 percent travel by public transportation, and the remaining by personal transportation. In order to increase the number of commuters traveling by public transportation from 42 percent to 50 percent, the city needs to add another 850 buses by 2009.
- APPCB will examine and plan for networking of "Pollution Under Control (PUC)" centers for the transmission of the emission test data to a central server to be located at the transport department. This is expected to help improve surveillance and track emission inspection status more effectively and check corruption. This system will be integrated with the vehicle registration data to enable tracking. Hyderabad already initiated a pilot project in 2006. APPCB will take the lead in modeling an implementation plan.
- The Department of Transport has submitted an action plan to control emissions from in-use vehicles like:
    - Euro-III norms for all new passenger cars and vehicles below 3.5 tons laden weight.
    - Bharat-II norms for all new buses/good vehicles.
    - Bharat-II norms for all new three-wheelers.
    - All in-use petrol-driven three-wheelers to be converted to LPG.
    - Phasing out of heavy goods carrier of +15 years.
    - Phasing out of heavy goods carrier of +20 years.
    - All petrol taxis to be converted to LPG.
    - No fuel at gas stations with PUC certification.
    - Government. vehicles older than 15 years to be replaced by Euro-III-complaint vehicles or converted to LPG
    - Permits to be cancelled for 10+ year diesel taxis.
    - No permits for taxis above 10 years.
- APPCB has identified and inventoried 333 air-polluting industries in the HUDA area, with details such as addresses, fuel used, control equipment provided, pollution load, and whether meeting the air emission standards is also outlined for inspection and control strategies. Based on a study conducted with the National Environmental Engineering Research Institute (NEERI), Nagpur, of the 333 industries, 301 are meeting the emission norms, seven are not meeting the emission norms, and 25 are closed. So far, 192 industries are fitted with air pollution control devices such as wet scrubbers, cyclones, multicyclones, bag filters, and dust collectors.
- Air pollution due to waste/vegetative burning in the city is one of the uncertain sources. The city is discussing better solid waste management

and the idea of including provisions for Clean Development Mechanism (CDM) facilities under approved landfill methodologies.

- Conduct routine wet street sweeping on roads with the highest traffic volume and eliminate dusty shoulders.

Box 2: Best Practices From Around the World

The list of best practices[39] presented below is a summary of various studies concerned with not only improving air quality as a primary target, but also reducing the carbon foot print of the city.

All, Clean Coal Technologies. Technologies are available to minimize SO_2 and NO_x emissions by removing the gas from the waste stream up to 90 percent.
Details from World Coal Institute
@ http://www.worldcoal.org/pages/content/index.asp?PageID=417

All, Bus Rapid Transport (BRT). BRT offers high-quality public transportation that can meet or exceed the performance of most rail systems at a fraction of the cost. BRT provides an alternative to personal vehicles, reduces GHG emissions, improves air quality, and promotes transit-oriented development. See the database of applications from the BRT Policy Center @ http://www.gobrt.org

Bangkok, Thailand. The MC upgrade project was voluntary, designed to improve awareness of good maintenance practices, improve through minor and major repairs the performance of ~300,000 MCs, and for the owners of eligible (i.e. most polluting MCs), provide a financial incentive in the form of a trade-in coupon to purchase a new clean MC.

Bogota, Columbia. A rapid bus transit system called Transmilenio throughout the city consists of 850 buses and has a demand of 1,400,000 passengers per day, Project costs are estimated at $1.3 billion US through Phase III.

Delhi, India. In 2001-02, all the public transport buses, three-wheelers, and most taxis, were converted to CNG-operated vehicles, resulting in an immediate reduction in local pollution levels.

Dhaka, Bangladesh. Municipal governments are approached to use solid waste as a resource by composting waste at five community-based plants, rather than burning or flaring it, and then selling it to fertilizer companies. The project is expected to receive CDM credits and costs estimated at $14,300 US.

Dongtan, China. Dongtan expects to use 64 percent less energy than a comparable city of its size built in a 'business as usual' way, with efficient lighting, pollution-free buses, waste-to-energy recovery systems, renewable energy for buildings, walkways, and state-of-the-art landuse planning.

Freiburg, Germany. The city reduced its energy consumption levels in various sectors via regulation, incentives, design, long-term commitment, and policy reforms, and by

[39] More details can be obtained from best practices section @ http://www.c40cities.org; For Dhaka and Bangkok @ http://www.worldbank.org; For Delhi @ www.rff.org

promoting solar power and energy efficiency. Project costs estimated at $58 million US.

Jakarta, Indonesia. A 12.9-km bus rapid transit corridor providing extensive bus services to 39 million people through the city. Project costs estimated at $2 million US per km.

London, UK. Congestion charging was first introduced into central London in February 2003 with a daily charge of £8 for driving or parking a vehicle on public roads within the congestion zone between 0700 and 1800 on Monday through Fridays, excluding public holidays. Project costs estimated at £300 million.

Mexico City, Mexico. A government-sponsored program to replace 10,000 of Mexico City's taxis that are at least 8 years old with more efficient models. The program has currently replaced 3,090 taxis, with significant improvements in fuel efficiency and fuel savings. Project costs estimated at $4.2 million US.

Rizhao, China. A city of 3 million people in northern China, households are using solar energy for 99 percent of their energy needs for heating and lighting.

Seoul, Korea. A voluntary program where people choose one day a week (Monday to Friday) as a no driving day. Participants are offered incentives (e.g., discounted petrol, free parking and car washing) provided by public organizations and private companies, to use alternate modes of transport on the selected days. Project costs estimated at $3 million US for inspection and maintenance.

Tokyo, Japan. A program to shift energy companies from fossil fuel use to a higher level of renewable energy, with expected 20 percent penetration by 2020.

Vietnam. The Vietnamese Energy Efficiency Public Lighting Project was co-funded by the Vietnamese government and the Global Environment Facility. The program covers the lighting of public sectors, including streets, schools, and hospitals, where all the costs for installation, operation, maintenance, and electricity are covered by the government. Project costs estimated at $15 million US.

7.3 Co-Benefits of Hyderabad City Action Plan

For the city of Hyderabad, the study analyzed the co-benefits for 2010 and 2020. Table 7.4 summarizes the results and expected range of benefits in terms of emissions of this analysis.

Table 7.4: Summary of Total Emission Reductions Under Hyderabad City Action Plan

	PM_{10}	SO_2	NO_x	CO_2
2006 Emissions BAU (tons)	29,599	11,577	44,877	7,138,538
2010 Emissions BAU (tons)	34,620	14,520	58,638	9,352,590
2010 Emissions—with controls (tons)	27,755	12,377	48,312	7,559,229
Estimated emission reductions (tons)	6,864	2,143	10,327	1,793,361

% Reduction from 2010 BAU	19.8%	14.8%	17.6%	19.2%
2020 Emissions BAU (tons)	43,550	18,670	63,694	10,310,520
2020 Emissions—with controls (tons)	24,110	13,365	40,059	6,968,693
Estimated emission reductions (tons)	19,440	5,035	23,635	3,341,847
% Reduction from 2020 BAU	44.6%	27.0%	37.1%	32.4%

For 2010 and 2020, Tables 7.5 and 7.6 present estimated individual reductions in PM_{10} and CO_2 emissions under each of the interventions. For 2020, the figures include reductions due to interventions introduced in 2010.

Table 7.5: Estimated Emission Reductions by 2010 Under Hyderabad City Action Plan

Intervention	PM_{10} (tons)	% Total	CO_2 (tons)	% Total
Replacing 50% old diesel buses to new and improved diesel buses	211	0.6	55,851	0.6
Converting all three-wheelers from petrol-based to LPG-based engines	847	2.5	105,847	1.1
Improving public transport	1,554	4.5	642,599	6.9
Wet and vacuum sweeping	630	1.8		
Inspection & Maintenance programs all the vehicles	202	0.6	154,670	1.6
Doubling emission standards for goods vehicles	1,317	3.8	834,393	8.9
Improving efficiency of dust collectors in industries by 25%	2,105	6.1		

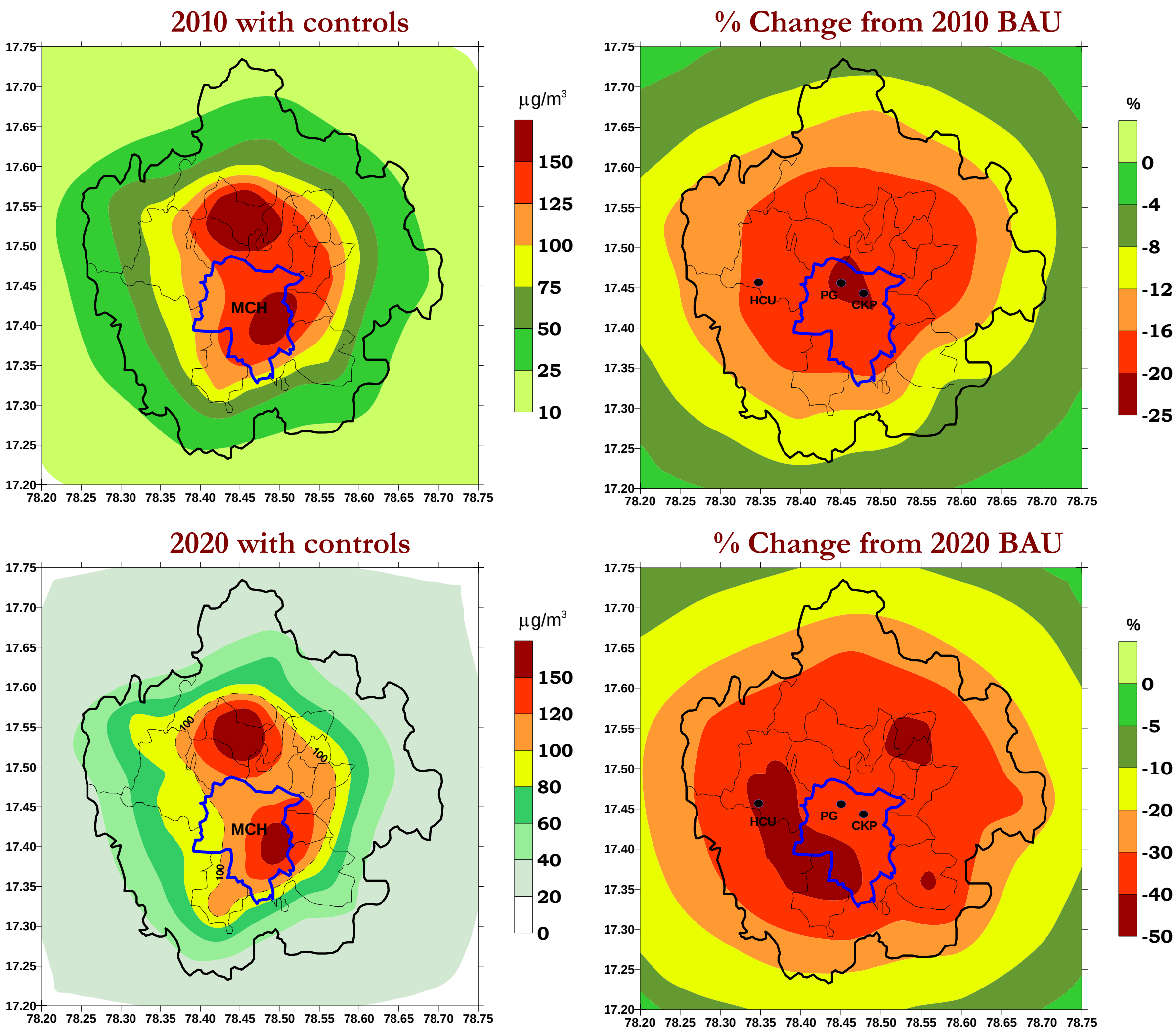
Table 7.6: Estimated Emission Reductions by 2020 Under Hyderabad City Action Plan

Intervention	PM_{10} (tons)	% Total	CO_2 (tons)	% Total
Introducing CNG buses for public transport for local and long distance in HUDA	5,034	11.6%	1,667,588	16.2%
Improving public transport	2,665	6.1%	1,014,646	9.8%
Improving wet & vacuum sweeping	2,990	6.9%		
Inspection & Maintenance programs all the vehicles	503	1.2%	391,969	3.8%
Abolishing diesel use for generator sets, wood, and husk in the industrial sector	6,201	14.2%	206,769	2.0%
Controlling illegal dumping and reducing landfill burning	693	1.6%		
Reducing coal use in the domestic sector	1,345	3.1%	60,854	0.6%

Under these scenarios, if planned and implemented, the emission levels are expected to fall below the 2006 BAU, with reductions ranging from ~20 percent and ~20 percent in 2010 and ~45 percent and ~32 percent in 2020 for PM and CO_2 emissions, respectively, compared to their corresponding BAU scenarios.

For ambient air pollution analysis, the simulated controlled scenarios were modeled using the same dispersion characteristics presented in Chapter 4. Figure 7.3 presents estimated annual average PM_{10} concentrations followed by percent reductions in ambient concentrations compared to their corresponding BAU scenarios.

Figure 7.3: Modeled Annual Average PM_{10} From 2010 & 2020 and Percent Changes From BAU



The ambient concentration reductions are substantial in the densely populated areas, mainly due to direct reductions in the transportation sector, which dominates these areas (also evident from the source apportionment studies). Note that these are reductions in the concentrations and don't translate and cannot be compared to direct reductions in emissions. Annual average concentrations ranged between 125 to 150 μg/m³ in 2010 and between 100 to 125 μg/m³ in 2020 in central HUDA areas. These concentrations are still higher than the WHO or national guidelines for residential and industrial areas, but when compared to the "what if" case of a BAU scenario, ambient concentrations are at least 20 percent lower in 2010 and at least 40 percent lower in 2020.

For the ambient concentrations presented in Figure 7.3, exposure analysis was conducted using the equations and DRFs presented in earlier chapters. The possible number of incurred cases and estimated reductions compared to BAU scenarios is presented in Table 7.7 for 2010 and 2020.

Table 7.7: Estimation of Health Impacts Based on Modeling Results for 2006

Health Endpoint	Number of Incurred Cases			
	2010 BAU	**2010 Control**	**2020 BAU**	**2020 Control**
Mortality	4,553	2,840	6,347	2,018
Adult Chronic Bronchitis	7,856	4,899	10,951	3,483
Child Acute Bronchitis	70,766	44,134	98,650	31,373
Respiratory Hospital .Admission	1,854	1,156	2,584	822
Cardiac Hospital Admission	1,626	1,014	2,267	721
Emergency Room Visit	76,555	47,744	106,720	33,939
Asthma Attacks	943,118	588,184	1,314,733	418,111
Restricted Activity Days	12,449,157	7,764,026	17,354,479	5,519,061
Respiratory Symptom Days	59,513,997	37,116,426	82,964,203	26,384,226

Using the data presented in Table 5.4, valuation of the health impacts was conducted for the estimated health impacts presented in Table 7.7. Under these control scenarios, total health costs incurred range from ~$266 million US or ~Rs.1,011 crores for 2010 to ~$189 million US or ~Rs.719 crores for 2020.

When compared to BAU scenarios, this translates to total savings of ~$160 million US or ~Rs.611 crores for 2010 to ~$405 million US or ~Rs.1,541 crores for 2020, in terms of health benefits.

The largest benefits for air quality are achieved via a combination of sweeping of paved roads; increasing moisture content on paved roads; converting three-wheelers to LPG; and improving industrial efficiency to PM capture.

As reflected in Table 7.4, carbon savings priced at $20 US per ton of CO_2 not emitted accounts for ~$36 million US or ~Rs.136 crores for 2010 and ~$67 million US or ~Rs.254 crores for 2020.

The largest benefits for GHG emissions are achieved via a combination of interventions for gross polluters—goods vehicles and buses, such as BRT

planning and improving fuel standards; introduction of inspection and maintenance to improve deterioration rates; and introducing LPG for domestic cooking.
The combined benefits of integrated air quality and climate change policies by 2020 (or earlier depending on the feasibility of accelerated actions) are expected to make substantial improvements in the city. Over time, technical and financial support for implementing measures will lead to a better urban environment. The health benefits of air pollution reduction outweigh the carbon savings, but carbon finances where available (and the value of estimated savings similar to health impacts) can be used to co-finance (and justify) projects that otherwise would not get implemented.

It is important to note that these are estimated reductions, and for each of the interventions, similar to the emissions estimation procedure, a more in-depth analysis is required to quantify these reductions. This analysis is usually conducted as part of the feasibility studies before and after project implementation.

Annex 1: Press Releases in Hyderabad, October, 2007

Times of India

@ http://timesofindia.indiatimes.com/articleshow/2493760.cms

THE TIMES OF INDIA, HYDERABAD
SATURDAY, OCTOBER 27, 2007

TIMES CITY

Poor air leaves city breathless

PCB Report Says Fine Dust Particles In Air Way Above Permissible Limits

TIMES NEWS NETWORK

Hyderabad: If you are suffering from chronic bronchitis, frequent bouts of cold and intermittent attacks of asthma, one of the reasons for your troubles could be the poor air quality in the city.

In a study to find out the share of different sources in the total air pollution in the city, AP Pollution Control Board found that the finer dust particle levels are above the standard level. "These dust particles whose diameter will be almost 500 times lesser than a millimetre can easily enter the respiratory tract and the lungs creating problems like congestion in the throat, cold and asthma. "These finer particles can enter the blood stream and might cause cancer," said K V Ramani, joint chief environmental scientist, APPCB here on Friday.

The study conducted between November 2005 and Dec 2006 by APPCB along with two other partners, US Environmental Protection Agency (USEPA) and the World Bank collected air samples from three different places in the city Punjagutta—busy junction; Chikkadpally—residential and industrial area; University of Hyderabad (HCU)—supposedly one of the less polluted areas in the city.

The alarming factor that came out of the study was that even at HCU, in winter, the concentration level of dust particles was above the standard level; 100 micro grams per metre cube. At Punjagutta, maximum reading of dust particles recorded was 218 and at Chikkadpally it was 261, far above the standard reading of 100 micrograms per metre cube.

The study said, road dust is the second major contributor to air pollution at 28 pc. "Earlier, we thought vehicular emission is the only major contributor to pollution," said K V Ramani. Methods like mechanised sweeping and complete paving of roads will reduce the problem by 50 pc, she added.

APPCB made some suggestions following the study: Improvement in quality of public transport; proper maintenance of roads, checking fuel adulteration, conversion of autos to alternative fuels and cap on number of public transport vehicles. The detailed report will be submitted in Nov, this year.

kicking up dust

Readings of the dust particles whose size is less than or equal to 10 micrometres taken from three different places in the city in three different seasons between November 2005 and December 2006

	Maximum	Minimum	Average	Standard
WINTER				
Punjagutta	188	127	160	100
Chikkadpally	163	110	134	100
HCU	123	94	106	60
MONSOON				
Punjagutta	218	28	111	100
Chikkadpally	261	45	113	100
HCU	105	14	64	60
SUMMER				
Punjagutta	193	56	122	100
Chikkadpally	130	34	86	100
HCU	100	23	59	60

Readings of dust particles whose size is less than or equal to 2.5 micrometres

	Maximum	Minimum	Average
WINTER			
Punjagutta	99	69	86
Chikkadpally	84	57	69
HCU	71	46	56
MONSOON			
Punjagutta	87	13	47
Chikkadpally	111	16	43
HCU	75	6	26
SUMMER			
Punjagutta	136	36	66
Chikkadpally	121	23	54
HCU	61	15	40

Note: The standard value for particles whose size is less than 2.5 micrometres has not been decided yet in India. In the western countries it is 30.

The Hindu
@ http://www.thehindu.com/2007/10/27/stories/2007102759600100.htm

City pollution: road dust is villain

K. Srinivas Reddy

HYDERABAD: Maintain the roads well and you can reduce air pollution by one third in Hyderabad.

The popular perception that citizens have a major stake in maintaining their vehicles properly to reduce air pollution has been debunked by a study conducted by the Andhra Pradesh Pollution Control Board. The board scientists found that road dust constituted a whopping 33 per cent of the total air pollution.

And the solution is pretty simple. Instead of squarely blaming the public, a policy intervention in ensuring 'continuous and good' maintenance of roads would check the problem to a large extent.

The study found that after the vehicular emission pollution (48 per cent), road dust took the next position by contributing a whopping 33 per cent. "Hitherto, everyone believed that 80 per cent of the air pollution was due to vehicular emissions. A little policy intervention in good and continuous maintenance of roads can reduce pollution," Dr. K.V. Ramani, a PCB scientist said.

Road dust constitutes the fine particles that remain suspended in air. A certain portion of the road dust could be because of the loose sand flying off from lorries or the ongoing construction works, but it is mostly from the dust flying off the road as vehicles pass by. The PCB scientists took measurement of dust (PM10 and PM2.5 – denoting particulate matter less than ten and 2.5 microns). Such fine dust particles easily enter the respiratory system.

Based on the study, scientists recommend that efforts should be made to improve the percentage of commuters using public transport from existing 30 per cent to 40 per cent, introduction of MRTS and BRTS, planning of ring roads and radial roads. Other measures include synchronisation of traffic signals, removing intercepts, evolving a parking policy, lane division on roads, checking adulteration of fuel, popularising use of alternate fuels etc.

The study was funded by the US Environmental Protection Agency and the World Bank. The US National Renewable Energy Laboratory and the Desert Research Institute, Nevada, U.S. provided technical support.